The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Aviation Occurrence Report

Loss of Control on Go-around (Rejected Landing)
Air Canada Canadair CL-600-2B19 C-FSKI
Fredericton Airport, New Brunswick
16 December 1997

Report Number A97H0011

Synopsis

Air Canada Flight 646, C-FSKI, departed Toronto-Lester B. Pearson International Airport, Ontario, at 2124 eastern standard time on a scheduled flight to Fredericton, New Brunswick. On arrival, the reported ceiling was 100 feet obscured, the visibility one-eighth of a mile in fog, and the runway visual range 1200 feet. The crew conducted a Category I instrument landing system approach to runway 15 and elected to land. On reaching about 35 feet, the captain assessed that the aircraft was not in a position to land safely and ordered the first officer, who was flying the aircraft, to go around. As the aircraft reached its go-around pitch attitude of about 10 degrees, the aircraft stalled aerodynamically, struck the runway, veered to the right and then travelled--at full power and uncontrolled--about 2100 feet from the first impact point, struck a large tree and came to rest. An evacuation was conducted; however, seven passengers were trapped in the aircraft until rescued. Of the 39 passengers and 3 crew members, 9 were seriously injured and the rest received minor or no injuries. The accident occurred at 2348 Atlantic standard time.

Other Factual Information

5.0 Appendices

1.0 Factual Information

1.1 History of the Flight

Air Canada Flight 646, a Canadair CL600-2B19 Regional Jet,[(1)]departed Toronto-Lester B. Pearson International Airport, Ontario, at 2124 eastern standard time (EST)[(2)] on a scheduled flight to Fredericton, New Brunswick. On board were two flight crew, one flight attendant, and

37 passengers plus two infants. The first officer, in the right-hand seat, had been assigned the pilot-flying (PF) responsibilities for this flight. The forecast and reported weather for the Fredericton Airport for the time of arrival was vertical visibility of 100 feet and horizontal visibility of one-eighth of a mile in fog. The runway visual range (RVR) was 1200 feet for the landing on runway 15 with the runway lights set to strength 5.

The flight was unremarkable until the aircraft was on final approach to the Fredericton airport. The autopilot was controlling the aircraft based on commands from the crew, the flight management system, and signals from the ground-based instrument landing system (ILS) for runway 15 at Fredericton. The aircraft's landing lights were on for the approach and landing. The captain saw the glow from the runway approach lights through the fog at about 300 feet above ground level (agl), 100 feet above decision height for the approach. At decision height, 200 feet above the runway, the captain, the pilot-not-flying (PNF), called the lights in sight and the first officer responded that he was landing. The first officer disconnected the autopilot, at about 165 feet above ground, to hand fly the rest of the approach and landing.

After the autopilot was disconnected, the aircraft drifted above the glide path, and twice the captain coached the first officer to get the aircraft down to the glide path. The first officer reduced thrust in response to the captain's first mention to get the aircraft down, and he reduced thrust to idle at about 80 feet agl. Moments later, the captain, aware that the aircraft was left of the centre line but not knowing the distance travelled down the runway, and not sure that a safe landing could be made, ordered a go-around, which the first officer acknowledged. The thrust levers were advanced, the first officer selected the go-around mode for the flight director, and he started to increase the pitch of the aircraft to the command bar indications, 10 degrees nose up. About one second after the first officer acknowledged the

go-around, the stick shaker (stall warning) activated. As the aircraft reached 10 degrees nose up, about one and one-half seconds after the stick shaker activated, the captain called flaps and selected them to the go-around setting, the warbler tone associated with the stall protection system (SPS) sounded, and the aircraft stalled aerodynamically. The aircraft rolled right to approximately 55 degrees of bank, and the right wing tip contacted the runway about 2700 feet from the threshold and 45 feet left of the centre line, the right wing tip bending upwards about four feet from the tip. The aircraft rolled left toward wings level, then, about 260 feet further down the runway, struck it again, this time banked about 20 degrees to the right with the nose down about 12 degrees. The nose wheel assembly broke off, the right winglet broke off, the radome and underside of the nose cockpit area were heavily damaged, and electrical power, except for emergency lighting, was lost. The aircraft rolled left onto its main wheels and, with the engines now at full power, departed the right side of the runway just past the intersection with runway 09/27. The aircraft plowed through the snow, on its main wheels, until it struck a ditch parallel to and about 200 feet from the runway. The tracks in the snow past the ditch were much lighter than the tracks left by the main wheels. These marks were made by flap fairings and aircraft equipment dangling on wiring still attached to the aircraft. The marks show that the aircraft became airborne after striking the ditch, very low to the ground, and flew in an arc to next strike a sand hill about 1000 feet right of the runway. Ground marks made by the aircraft were largely obliterated by traffic during the rescue, and it could not be determined where the aircraft first hit the hill; however, there were pieces of the aircraft near the bottom of the hill. At the top of the hill, the aircraft slewed to the right, struck some trees, one approximately 22 inches in diameter, and came to rest. The aircraft stopped on a heading of 314 magnetic, about 1130 feet west of the runway and 2100 feet from the first impact point on the runway. See diagram at Appendix B1.

The right engine stopped at the top of the hill. The left engine continued to run for a few minutes to 15 minutes (by witness accounts), and the captain finally managed to shut it down with the engine thrust lever. After the aircraft struck the runway and during its excursion, the crew were not able to control the aircraft because of the darkness inside and outside the aircraft, aircraft damage, disorientation, and the roughness of the ride. There was no post-crash fire. The time of the accident was 2348 Atlantic standard time(AST).[(3)]

An emergency evacuation of the aircraft was conducted. Seven passengers had to be extricated from the aircraft by emergency response personnel, the last one at 0234. Of the 42 persons on board, 35 were sent to hospital, and 9 were hospitalized.

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	0	0	0	0
Serious	1	8	0	9
Minor/None	2	31	0	33
Total	3	39	0	42

1.3 Damage to Aircraft

The aircraft remained generally intact, with no damage to the empennage and damage to the top of the aircraft limited to the tear caused by the large tree. Damage to the wings was limited to an indentation on the leading edge of the left wing, caused by striking either the ground or a tree, and the inboard flaps were damaged by ground contact. The winglet of the right wing bent upwards on runway contact but remained attached to the wing until just before the aircraft stopped. The underside of the cockpit and nose area, back to the avionics bay door, was demolished by the departing nose gear and contact with the runway and ditch. The wreckage trail was strewn with electronic equipment and structure from the nose area, and with the three landing gear and associated structures. The underside of the aircraft, from the landing gear area aft to the rear fuselage equipment bay door, was damaged by the separating landing gear and by impacts with the ditch and the hill. The aircraft struck the tree at the passenger door, the tree remaining intact. As the aircraft moved forward, the tree cut through the aircraft cabin to a point about nine feet aft of the door, just left of the centre line of the aircraft. Apart from damage where the tree had torn through the aircraft, the rest of the cabin floor, seat rails, seats, and overhead bins showed no signs of deformation or damage. The area of the aircraft ahead of the galley, looking forward, was twisted counter-clockwise a significant amount.

1.4 Other Damage

There was no other damage except to some vegetation where the aircraft stopped.

1.5 Personnel Information

1.5.1 General

	Captain	First Officer
Age	34	26
Pilot licence	Airline Transport	Airline Transport
Medical expiry date	June 1998	June 1998
Total flying hours	11 020	3225
Hours on type	1770	60
Hours last 90 days	217	60
Hours on type last 90 days	217	60
Hours on duty prior to occurrence	7	7
Hours off duty prior to work period	17	24

1.5.2 Captain

The captain began his flying training in 1979, enrolled in the Seneca College of Applied Arts and Technology in 1982, and graduated in May 1985 with an Aviation Flight Technology Diploma. Between June 1985 and May 1987 he worked at Pem Air, beginning his employment as a flight instructor and finishing as Senior Base Captain and Manager of the flight school. In May 1987 the captain moved to Voyageur Airways, where he flew the King Air BE-100 aircraft as a line pilot and performed the duties of training captain for all BE-100 crews. He joined Air Nova in May 1988 flying DHC-8 aircraft, starting as a first officer and progressing to captain and training pilot. He flew for Air Nova for seven years, six years as a captain. In June 1995 he joined Air Canada as a first officer on the CL-65. He was promoted to captain in October 1996, and in October 1997 he qualified to carry out the duties of a line indoctrination captain. Of his 1770 hours on the aircraft type, just over 975 were as captain.

At the time of the occurrence, the captain held a valid Category I medical certificate and a Group I instrument rating, in effect until September 1998. His last Pilot Proficiency Check (PPC) was conducted in July 1997, and was valid until January 1998. He was qualified for Category II landings.

1.5.3 First Officer

The first officer attended Seneca College of Applied Arts and Technology, graduating May 1993 with an Aviation Flight Technology Diploma. In May 1993 he was hired by the Toronto Flight Centre as a flight instructor on Cessna aircraft. In February 1995 he moved to ATR Inc., a Toronto Island-based charter company. He was both a charter pilot and a flight instructor for ATR until February 1996, when he joined Grand Aviation. While at Grand Aviation, he was a charter pilot on a Piper Cheyenne II. In September 1997, he became a first officer on the CL-65 with Air Canada, completing 85 hours of ground school training and 36 hours of simulator training, including his PPC and an instrument flight test. Between November 22 and December 5 he accrued just over 29 hours' flight time during line indoctrination. During those flights he flew 10 legs as PF and 7 as PNF. Following his line check on December 9 he was qualified to fly as first officer on the aircraft. His remaining hours on type were accrued between December 10 and 16.

At the time of the occurrence the first officer held a valid Category I medical certificate and a Group I instrument rating, in effect until June 1998. His initial CL-65 PPC was conducted in November 1997, and was valid until June 1998. He was qualified to perform the duties of the PNF for Category II landings. He also held valid instructor and aerobatic instructor ratings.

1.5.4 Cabin Crew

The cabin crew comprised one flight attendant, seated in the assigned jump seat (L1 door) at the time of the occurrence. He had approximately 28 years' experience with Air Canada, two of which were on the CL-65 aircraft, and was qualified on all other aircraft in the Air Canada fleet. Coincidently, an Air Canada CL-65 flight attendant was travelling as a passenger (Seat 3E). She had been with Air Canada for one and a half years and was qualified on all aircraft flown by Air Canada.

1.6 Aircraft Information

1.6.1 General

Manufacturer	Bombardier Inc., Canadair
Type and model	CL-600-2B19
Date of manufacture	April 1995
Serial number	7068
Certificate of Airworthiness (Flight Permit)	19 May 1995
Total airframe time (hours) / Cycles / Landings	6061.23 / 5184 / 5135
Engine type (number of)	General Electric, Model CF34-3A1 (2)
Maximum allowable take-off weight	51 000 pounds (23 133 kilograms)
Recommended fuel type(s)	Jet A, Jet A1, JP5, JP8, Jet B, JP4
Fuel type used	Jet A1

The amount of fuel removed from the aircraft after the occurrence was 2230 litres (1825 kg), and baggage off-loaded weighed 1064 kg. The estimated weight at the time of the occurrence was 44 180 pounds (20 036 kg) based on the planned take-off weight of 22 000 kg from Toronto and the fuel burn estimated from fuel-flow data on the flight data recorder (FDR). Documented data and calculations show that the aircraft was within the weight and centre of gravity limitations for the entire flight.

1.6.2 Aircraft Systems

1.6.2.1 Flight Director

The CL-65 automatic flight control system (AFCS) is an integrated autopilot and flight director, the flight director providing visual guidance by means of a magenta "V" bar on the attitude director indicator. The crews use the V-bar guidance to fly the aircraft in response to the pitch and roll guidance commands generated by the flight control computers. The flight director system provides commands to perform the following vertical modes: pitch, holds a desired pitch attitude; take-off, generates a 15-degree pitch-up command, changing to 10 degrees if there is a loss of an engine; altitude preselect; altitude hold; speed; vertical speed; glide-slope; and go-around, generates a 10-degree pitch-up command. At a given time, the flight director can command one vertical and one lateral mode.

The aircraft operating philosophy stresses that flight director commands be followed for effective flight control. However, using the command bars as the sole guidance for vertical modes does not always ensure safe flight and, for that reason, additional guidance is provided in operating limitations and standard operating procedures (SOPs) to ensure that the aircraft stays within its certified flight envelope. Pertinent to this occurrence, in the go-around mode, pitch guidance did not take into account aircraft configuration, airspeed, angle of attack (AOA), or other performance parameters. Such an arrangement is common, and certification and equipment standards do not require that flight director guidance be linked to performance parameters.

The ground proximity warning system in the CL-65 has been programmed to detect wind shear, and escape guidance is then generated by the flight control computer. The escape guidance is based on inputs of airspeed, AOA, aircraft pitch, radio altimeter height, and flap configuration, with the output generated on the flight director command bars. Escape guidance pitch command limits are based on aircraft altitude and AOA. Below 50 feet, the pitch command is limited to the stall warning (stick shaker) AOA, while between 50 and 400 feet, the command is limited to two degrees less than the stall warning AOA. Pitch-limit (alpha-margin) indicators appear on the primary flight display depicting the amount of pitch attitude change that can be made before the airplane reaches the stick shaker AOA. There are no similar computations or indications when go-around is selected; the command bars indicate 10 degrees nose-up.

1.6.2.2 Stall Protection System

During the initial stages of an aerodynamic stall of the CL-65, the local airflow separation on the wing is minimal, and the level of buffet from the airflow separation cannot be considered a significant cue to stall warning. Because of its lack of normal stall warning, the aircraft was equipped with an SPS. The SPS comprises a stick shaker device to indicate that the stall speed is being approached and a stick pusher to cause the aircraft to pitch down, if necessary, to keep the aircraft from actually stalling.

AOA information is obtained from two AOA vanes, one on each side of the nose of the aircraft. The SPS computer, with two independent channels, uses this AOA information, combined with Mach, flap position, and lateral acceleration to signal the crew of impending stall and to prevent the aircraft from entering a stall. When the AOA is changing, the computer notes the rate of change and, if necessary, applies a correction to activate the protection system ahead of its normal trip points.

When the aircraft is airborne, the SPS computer continuously monitors inputs to determine the SPS AOA trip points. There are three trip points, each at a higher AOA, which initiate the following actions:

- -Auto-ignition--when either AOA vane reaches this trip point, continuous engine ignition is activated as a precaution against engine flame-out at high aircraft AOA.

- -Stick shaker--when either AOA vane reaches this trip point, the respective shaker is activated and the autopilot is disengaged. Because the control columns are interconnected, the shaking can be felt on both control columns.

- -Stick pusher--when either AOA vane reaches this trip point, the warbler sounds and the STALL/switch lights on the glareshield panel flash red. The pusher activates when both AOA vanes reach the pusher trip points.

The stick pusher mechanism is designed to prevent the aircraft from entering an aerodynamic stall by applying a control column force to pitch the aircraft nose down as the aircraft reaches its computer-calculated pusher (stall) AOA. The *Canadair Regional Jet Airplane Flight Manual* (*AFM*) contains a chart (page 06-01-23) which allows calculation of the aircraft stick pusher (stall) speed for various aircraft weights. For 44 180 pounds, the aircraft's estimated weight at the time of the accident, with the flaps set at 45 degrees and the landing gear down, the pusher activation speed would have been about 109 knots calibrated (109 knots indicated) at one g. At the moment of the aerodynamic stall, the aircraft was at a g loading of about 1.227, and the pusher activation speed would have been about 120 knots, the natural stall speed would have been about 116 knots, and the pusher activation AOA would have been about 13.5 degrees.[(4)] At the moment of stall, the flaps had retracted a few degrees from 45 and the g was increasing, both of which would cause a slightly higher pusher activation speed; however, there would be no effect on the pusher activation AOA.

Information from the flight recorders indicates the following events occurred during the attempted go-around: the stick shaker activated when the aircraft was at 129 knots as the pitch was being increased through 4 degrees; and the right roll and stall onset occurred and the warbler tone activated when the aircraft was at 124 knots and with the pitch at 9.7 degrees. At the time the warbler sounded, the left and right AOA vane readings were approximately

8.7 degrees and 9.4 degrees, respectively. The pusher did not activate because, while the right AOA reached its trip point, the left AOA did not.

1.6.2.3 Airspeed Indications

The aircraft is equipped with dual air data computers that use pitot and static pneumatic inputs and total air temperature data to produce the following airspeed information, displayed on the left side of the primary flight displays: indicated airspeed, indicated Mach, airspeed trend vector, maximum speed (Mach and indicated airspeed), over-speed warning, stall margin, and stall warning.

Indicated airspeed is presented as a white moving tape with a fixed pointer that indicates current airspeed. A magenta trend vector indicates predicted airspeed within the next

10 seconds. The magenta airspeed reference bug moves along the airspeed tape as set by the pilot using the speed knob. The reference bug spans five knots either side of the centre pointer, and is the primary speed reference; standard operating procedures require that the bug be set to the appropriate target speed for all phases of flight. A red/black checkerboard band is displayed on the speed tape, starting from the calculated stall speed to the bottom of the tape, and acts as a cue that the aircraft speed is getting low. Prior to descent, the V_{FTO} and V_2 are set by the pilot and are displayed in cyan on the airspeed tape. V_{FTO} is the single-engine climb speed, and V_2 is the take-off safety speed, both used if conducting a go-around but not used during a normal approach. On final approach, the airspeed reference bug is set to V_{REF} plus Factor.[(5),(6)]

The expected landing weight was 20 200 kg (44 530 lbs). The V_{FTO} was set to 173, and

V_2 set to 145, the take-off safety speed for flaps 8 and, on final approach, the airspeed reference bug was set, in accordance with Air Canada's SOPs, to 144 knots (V_{REF} plus 5 knots).

1.6.2.4 Flaps

The CL-65 is equipped with double-slot type flaps that are moved by two electric motors in response to the flap lever commands; one flap motor will operate the flaps at reduced speed. The flap setting for the landing configuration is 45 degrees. During a go-around the flaps are selected to the 8-degree position. The flaps move at a constant speed, taking about 13.5 seconds for the flaps to move through the 45 degrees during retraction and extension. It takes about

11 seconds for the flaps to move from 45 to 8 degrees.

FDR data indicate that the flaps started travelling up from 45 degrees coincident with the captain calling "FLAPS" and the warbler tone sounding. When the aircraft was examined following the accident, the flaps were found at 24 degrees.

1.7 Meteorological Information[(7)]

1.7.1 General

The aftercast produced by the New Brunswick Weather Centre, Environment Canada, indicated that on the evening of 16 December 1997 a warm front moved across New Brunswick. Stratus and extensive fog persisted in the warm sector for the remainder of the night. Satellite information for the period of 16/1400 to 17/0800 shows that the warm front progressed over New Brunswick as predicted and that the trailing, weak cold front remained west of the region during the period.

1.7.2 Forecast Weather

The clouds and weather area forecast issued at 16/1930 for the warm sector in New Brunswick at the time of the accident was for scattered, occasionally broken cloud based at 3000 feet above sea level (asl) topped at 5000 feet, a scattered layer at 8000 feet topped at 12 000 feet, with high scattered cloud above and visibility 6 statute miles (sm). The forecast also included patchy stratus cloud ceilings 200 to 600 feet agl, and visibility 1 to 3 miles in fog/mist, especially in low-lying areas.

The following terminal area forecast for Fredericton, issued at 16/1840 and valid for the period 16/1900 to 17/0700 was provided to the crew in their pre-flight briefing package:

- forecast winds from 180 degrees at 5 knots, visibility 6 sm, scattered clouds at 1000 feet agl, broken clouds at 4000 feet; temporary conditions between 16/1900 and 16/2100 of 1.5 miles visibility in light snow showers and overcast cloud at 400 feet agl.

- from 16/2100 the winds would be from 200 degrees at 6 knots, visibility 6 sm, scattered cloud at 400 feet and broken clouds at 2500 feet; temporary conditions between 16/2100 and 17/0200 broken cloud at 400 feet and overcast clouds at 2500 feet, becoming between 17/0100 and 17/0300 winds 240 degrees at 8 knots.

The following 16/2139 amended forecast for Fredericton, valid between 16/2100 and 17/0700, was provided to the crew at 16/2310 by the Air Canada dispatcher using the automated aircraft communications and reporting system (ACARS):

- winds variable at 3 knots, visibility ¼ mile in fog, vertical visibility 100 feet, with temporary conditions between 16/2100 and 17/0700 visibility 4 sm, scattered clouds at 400 feet, and broken clouds at 1500 feet.

1.7.3 Actual Weather

The accident occurred at 2348. The actual weather for Fredericton was reported as follows: at 2125, 2149, and 2200 the wind was calm, visibility ¼ sm in fog, vertical visibility 100 feet, temperature -8C, dew point -8C, remarks 8/8 sky coverage in fog. At 2300, 2357, and 2400 the conditions were the same except the visibility was reported as sm in fog, and at 2300 the RVR for runway 15 of 1000 feet was included.

Following the flight's departure from Toronto, an Air Canada dispatcher provided weather updates to the crew via the ACARS; the 2300 weather was passed to the crew by ACARS at 2310. In addition, the crew was provided with the weather information by air traffic control. At 2328 they received from the Flight Service Station (FSS) specialist: 2300 wind calm, visibility, RVR15 1000 feet in fog, vertical visibility 100 feet, temperature -8C, dew point -8C, altimeter 29.82. At 2328 the RVR was 1400 feet with light setting 5. At 2335, 2341 and 2346 the RVR15 was passed as 1200, with light setting 5.[(8)]

Based on the FDR data, the winds on final were calculated to have been 238 magnetic at

34 knots at 1000 feet asl, 246 at 17 knots at 500 feet, and 256 at 10 knots at 200 feet.

The weather at the crew's alternate airport, Saint John, at 16/2300 was reported as visibility 8 miles, a few clouds at 300 feet, broken cloud at 1400 feet, temperature +3C, dew point +2C, altimeter setting 29.82 inches. The weather at 16/2400 was reported as visibility 8 sm, overcast cloud at 1800 feet, temperature +3C, dew point +1C, altimeter setting 29.80.

1.7.4 Icing Conditions

The area forecast for the New Brunswick area behind the warm front indicated that, for the time of the occurrence, there would be light, occasionally moderate icing in cloud. The freezing level would be at the surface, with above-freezing layers between 3000 and 6000 feet asl. The Caribou, Maine, tephigram[9] for 16/2000 indicated a sharp temperature inversion aloft. The upper-level winds forecast for the Fredericton area, valid for use between 16/1700 and 17/0200, indicated above-freezing temperatures up to and including 9000 feet asl. The Surface Weather record for Fredericton indicates that at 16/2300 the dry-bulb/dew-point temperatures were -7.7C/-8.3C, and at 16/2357, -7.6C/-8.1C.

The crew reported that the flight was not in cloud until the final stages of the approach into Fredericton, where they entered cloud at between 500 and 1000 feet agl, and that there were no indications of icing throughout the flight. In the two hours before the occurrence, two flights had landed at Fredericton in similar weather conditions. During the investigation, the crew of one flight indicated that on final approach, after entering cloud, there was some light icing, and after landing there was some light rime icing on the leading edge of the wing. The crew of the other flight did not see ice during the approach or on the wings after landing. A person driving from Edmundston to Fredericton on the evening of the accident reported encountering freezing fog north of Fredericton.

1.8 Aids to Navigation

The airport is served by a VOR (very high frequency omni-directional range) and a non-directional beacon. They provide for non-precision approaches to runways 09, 15, and 27. Runway 15 is also served by an instrument landing system (ILS) that provides a Category I approach, the only precision approach to the airport (Appendix A). The ILS decision height is

200 feet above the touchdown elevation. The FSS is equipped to monitor and control the ILS, and there were no abnormalities displayed at the time of the occurrence. A special flight check , conducted by NAV CANADA on December 17, showed the ILS to be operating normally.

Air Canada CL-65 aircraft are equipped with: dual VHF (very high frequency) radios, providing VOR, localizer, glide slope, and marker-beacon information; dual ADF (automatic direction finder); dual DME (distance measuring equipment) navigation systems; and an ATC (air traffic control) transponder system. The aircraft is also equipped with weather radar, TCAS

(traffic-alert and collision-avoidance system), ground proximity warning system, and an FMS (flight management system). The FMS is an integrated navigation system that provides

point-to-point and great-circle navigation using its integral data base, dead reckoning, and VOR and DME information.

The crew used the FMS for the en route portion of the flight and for the descent to the approach, and flew the ILS Rwy 15 approach at Fredericton. The crew reported that all aircraft and ground systems were functioning normally.

1.9 Communications

The aircraft is equipped with dual VHF communication radios; both radios functioned normally during the flight.

The aircraft is also equipped with an aircraft communications and reporting system (ACARS), used by Air Canada operations to monitor flight progress and to communicate between the flight dispatch centre and the aircraft. The ACARS aircraft-based and ground-based systems functioned normally throughout the flight.

During the arrival of Flight ACA646, communications were normal and appropriate between the flight crew and the FSS specialist. Weather information was passed to the crew in a timely manner.

1.10 Aerodrome Information

1.10.1 General

The Fredericton airport is certified, operated by Transport Canada, and meets current regulations as specified in the *Canadian Aviation Regulations* (CARs). The airport is now uncontrolled, in that there are no longer tower controllers at Fredericton to control local air or ground traffic; however, there is still a control tower structure at the airport. FSS specialists operate 24 hours a day, every day, out of the tower. The airport has two runways, 15/33, which is 6000 feet long, and 09/27, which is 5100 feet long; both are 200 feet wide and asphalt surfaced.

1.10.2 Runway Lighting and Runway Visual Range

Runway 15 is equipped with high intensity approach lighting with runway alignment indicator lights, threshold and runway end lights, and high intensity runway edge lights. The intensity of these light systems can be varied from a setting of 1 to 5, with the lights brightest at setting 5. At the time of arrival of ACA 646, the lights were at setting 5. All lighting was reported to be working at the time of the accident.

RVR equipment is installed for runway 15, with the optical equipment located near the ILS installation on the south side of runway 15, approximately 1100 feet from the threshold. A computer combines information from the ambient light sensor and the runway light intensity setting to produce a visibility value, in feet, that is displayed at the operations console in the FSS. The RVR is displayed in 200-foot increments from a minimum value of 600 feet to 4000 feet, and in 500-foot increments above 4000 feet to a maximum value of 6000 feet. There is no recording capability for storing past RVR values, but the RVR equipment does display, record and store error messages. There were no recorded error messages at the time of this accident.

1.10.3 Runway Condition

A snow- and ice-control crew was on duty on the night of the occurrence. The last full runway length James Brake Index (JBI) reading on runway 15 had been completed about 50 minutes prior to the arrival of ACA 646; the JBI was .48.[(10)] At the time, the runway was 60 per cent bare and dry and 40 per cent covered with ice patches. The runway was then sanded, and an abbreviated JBI reading was taken in the touchdown area for runway 15 a few minutes prior to the arrival of ACA 646; the JBI was .40. This information was passed to the crew of ACA 646.

1.10.4 Air Traffic Services

Instrument flight rules (IFR) ATC services for the Atlantic region, which includes the Fredericton area, are provided by controllers in the Moncton Area Control Centre (ACC). The crew of ACA 646 was provided with appropriate clearances and airport information by the Moncton ACC controller. Once ACA 646 was established on final approach 18 miles northwest of the airport, the pilot was instructed to contact Fredericton FSS.

The Fredericton FSS specialist, located at the airport, is responsible for providing airport advisory service to pilots; ground vehicle control service; operation of runway, approach, taxi, and other airport lighting; 24-hour weather observations; NOTAM service; VFR alerting service for the Fredericton control zone; and support, monitoring, and serviceability reporting in accordance with established agreements. Staffing was in accordance with local policies and was compatible with the workload.

The specialist working on the night of the accident was qualified and certified. He had over

19 years' experience in FSS operations and had been working at Fredericton for the past two years. He had been on duty since 2000 and was working alone. There was no other air traffic in radio communication with the FSS, and all vehicles were clear of runway 15. The FSS specialist had passed to the crew of ACA 646 all information required by rules and procedures governing FSS operations.

Once contacted by ACA 646, the specialist advised the crew of the weather and runway conditions at the Fredericton airport. When ACA 646 reported nine miles on final approach, the specialist issued the latest runway conditions as received from the airport maintenance foreman and confirmed that runway 15 was clear of all vehicles. The last radio contact between the FSS and ACA 646 was when the aircraft reported abeam the Fredericton NDB and was provided a wind check (calm) and an RVR reading of 1200 feet with approach and runway lights set at intensity 5 (maximum). No other communications were expected until the aircraft landed or commenced a missed approach. When the expected arrival time had passed and nothing further from ACA 646 was heard by the specialist, he conducted a communications search, coordinated with Moncton ACC, and initiated a runway search by airport maintenance and emergency response workers.

At uncontrolled airports, the pilots of all aircraft are responsible for providing their own separation from other aircraft, and they make their decision to take off or land based on known traffic and the suitability of the runway: the pilots do not require a clearance to take off or land. At controlled airports, tower controllers provide the same advisory service as would an FSS specialist; however, a pilot is not allowed to take off or land until cleared to do so by the controller, based on knowledge of other ground and air traffic. For ACA 646, on an IFR flight, the issuance of landing clearance would have been the only additional communication had there been a tower controller at Fredericton rather than a FFS specialist. In this instance, a tower controller undoubtedly would have cleared ACA 646 to land, as there was no valid reason for not doing so.

1.11 Flight Recorders

1.11.1 General

The flight data recorder (FDR) and cockpit voice recorder (CVR) were recovered from the wreckage by the TSB and taken to the TSB Engineering Branch for playback and analysis. Both were undamaged and contained good data.

1.11.2 Flight Data Recorder

The FDR is a Loral F1000 solid state recorder, part number S800-2000-00, serial number 00943. The recording contained just over 60 hours of information. The TSB's Recovery, Analysis and Presentation System was used to recover the entire occurrence and previous flights from the FDR. The occurrence flight data were found to be of very good quality and contained no synchronization drop-outs or data losses prior to the second runway impact. Approximately four seconds after the time of the second impact, there was a loss of data estimated to be a few seconds in duration. The loss of FDR data was likely due to a power interruption and/or data acquisition system damage due to subsequent impact with the ground, likely the ditch. The landing data were provided to the FDR manufacturer who, using manual data recovery techniques, recovered approximately the last five seconds of data following the data loss.

Some of the last-recorded data appear to be valid despite the probable influence of impact damage; the recorded left and right engine N_1 fan speeds are about 94% on the left and 92% on the right. The last three recorded samples of heading, approximately 271, did not match the 314 heading of the aircraft at rest, suggesting that the FDR stopped functioning just before the aircraft came to rest. The flaps were found at the 24 degrees extended position, and the FDR indicated that the flaps were retracting through approximately 28 degrees at the time of the data loss. Given the unreliable data, it could not be determined precisely when the FDR stopped functioning.

1.11.3 Cockpit Voice Recorder

The CVR is a Loral A100A, part number 93-A100-83, with serial number 62289. The CVR recorded the captain, first officer and cockpit area microphone audio channels. The communications were easily intelligible, primarily because the flight crew had their intercom microphones on at all times.

The CVR recording was digitized into the TSB's computer systems for analysis and transcription. The recording began with the aircraft in cruise flight at FL330, approximately

15 minutes prior to descent, and ended approximately four seconds after impact with the runway.

The CVR stopped recording at the time of the FDR data loss, approximately four seconds after the second impact on the runway. The CVR was equipped with an impact unidirectional inertia switch that opens, shutting off the CVR, if the aircraft experiences deceleration in the longitudinal axis greater than two G; longitudinal decelerations at the second impact were less than two G. It could not be determined whether the CVR stopped because of g loads or because of damage as the aircraft struck terrain off the runway. The international flight recording community considers the use of a G-switch to shut off the CVR an unreliable method of stopping the CVR, and there is concern that a G-switch could prematurely stop the CVR.[11]

1.11.4 Flight Reconstruction

A computer animation of the flight was developed to help determine the sequence of events and to determine a time history of the aircraft's position relative to the runway during the attempted go-around. Information from the aircraft recorders, ATC, the pilots, and marks left on the runway was used in the preparation of the animation.

Information from the flight reconstruction was used in the description of the flight and in the investigation of operational and performance issues.

1.12 Wreckage and Impact Information

The galley service door could not be opened by investigators after the crash. Some panels were removed and the door's operating mechanism was examined and operated as much as it could be. The mechanism was undamaged, and it operated normally until the rear corner of the door contacted the aircraft skin, which prevented further movement of the door. Looking forward, the cockpit area was twisted counter-clockwise with respect to the cabin, probably a result of impact with the tree. This twisting was enough to cause the door to be out of alignment and jammed. It was concluded that the door would have operated normally had it not been jammed.

The aircraft flap selector was found selected to Flap 8 (go-around) position, and the flaps were positioned at about 24 degrees. It was concluded that the flaps had not had time to move to

8 degrees before electrical power to the flaps was lost. The spoilers were retracted and seated very close to being flush with the adjacent structure, and FDR data indicated that they were retracted.

Both main landing gear had separated from the aircraft. The brackets that hold the pivot points into the upper ends of the landing gear legs had fractured, allowing the upper ends of the landing gear legs to slide cleanly away. This design minimizes damage to the wings during an accident involving the landing gear to reduce the likelihood of fuel spillage from the wings, and of fire. The nose gear and part of the strut assembly broke away on impact with the runway, and the rest of the nose gear structure broke away at the ditch.

The positions of valves that govern the supply and distribution of engine bleed air were checked: both 14th stage bleed air shut-off (supply) valves were open; both modulating/shut-off valves for the wing anti-icing system were closed; and both pressure-regulating and shut-off valves for the engine cowl anti-icing system were closed. These positions are those to which the valves are designed to move when electrical power to the valves is removed. The anti-ice switches were both OFF, which also coincides with the valve positions.

The instrument panel, especially the glass instrumentation, was substantially damaged by impact forces; it was also somewhat damaged during the captain's attempts to shut down the left engine.

After the aircraft came to rest both engines were running at high power. The crew pressed the fire switches to shut down the engines; however, the fire switches were inoperable as there was no electrical power on the flight deck. The captain attempted to shut down the engines by moving the thrust levers to the shut-off position. The right engine shut down at the same time that the right thrust lever was retarded; however, as the right engine fuel line was found broken, the engine could have stopped either because of the fuel being shut off or because of fuel starvation. The left thrust lever could not be pulled back. The captain got out of his seat, braced his foot on the instrument panel and succeeded in pulling the thrust lever aft, and the engine stopped. It was found that the left engine cable had been stretched taut and damaged as the tree entered the aircraft, making it difficult to move the left thrust lever.

The day after the accident, persons employed by Air Canada painted over the Air Canada trademarks and name on the aircraft. There was some confusion regarding the permission to paint; however, there was no damage done in painting over the trademarks and name, and no information needed by the investigation team was interfered with, obliterated, or lost. The TSB has established measures to prevent future confusion regarding such painting.

1.13 Medical Information

Based on the 72-hour history of the pilots and the circumstances of the accident, no medical, physical, or psychological factors were identified that negatively affected either pilot's performance during this occurrence.

1.14 Fire

There was no fire, either before or after the aircraft crashed.

1.15 Survival Aspects

1.15.1 General

Once the aircraft came to rest, an emergency evacuation of the aircraft was conducted. Seven passengers had to be extricated from the aircraft by emergency response personnel. Of the

42 persons on board, 35 were sent to hospital; 8 passengers and the captain were admitted. Some minor injuries were incurred when passengers evacuating via the over-wing exits slipped and fell on the slippery wing surface.

All the passengers who incurred serious injury were located in the first four rows of the passenger cabin, seven passengers on the left side of the aircraft, at or just aft of the point where the tree broke through the fuselage on impact, and one on the right.

1.15.2 The Aircraft

At the time of the occurrence, there were 50 passenger seats on the CL-65. There were 12 rows of seats with 4 seats per row, lettered from the left A, B, C, and E, and one row, 13, with 2 seats, both on the left side. There were 37 adult passengers and two lap-held infants on this flight. The passengers travelling with infants were seated in 1E and 12E. There were no empty rows on the aircraft, and there were no persons with disabilities on the flight.

The aircraft is equipped with five emergency exits: one passenger door, one galley service door, two over-wing exits and one flight deck escape hatch. In a belly landing, the galley service door and the over-wing exits are the primary exits; the passenger door is considered an alternate exit because the attitude of the aircraft may interfere with the operation of the stairs. The flight deck escape hatch is to be used as a last resort in any evacuation. In this occurrence, the passenger door was torn from its mountings and left jammed across the door sill area when the tree broke through the fuselage. The galley service door was jammed during the crash; the captain attempted to open the door but was unable to do so. Both over-wing exits were serviceable and used during the evacuation. The escape hatch was not used. The fact that the galley service door could not be opened did not greatly impede the evacuation.

Emergency equipment is found in various areas of the aircraft. Included in the equipment, and of interest in this occurrence, are an axe, a pry bar, and four flashlights. Three flashlights are located on the flight deck and one is located under the flight attendant's seat. The pry bar is located in the fire-fighting kit in the wardrobe unit.[(12)] Emergency equipment used in this occurrence were flashlights and the crash axe.

CAR 602.61 (1) states, in part, that an aircraft operating over land must carry survival equipment that provides a means for "(d) visually signalling distress." CAR 602.61 (2) states that this requirement does not apply in respect of "(c) a multi-engine aircraft operating south of 6630' north latitude (i) in IFR flight within controlled airspace, or (ii) along designated air routes."

The aircraft emergency lighting system consists of floodlights for illumination of the passenger cabin and entrance areas, lighted exit signs, exterior evacuation floodlights at the doors and over-wing exits, and an escape-path lighting system at floor level. Emergency power is supplied for approximately 15 minutes when fully charged. In this occurrence the emergency lighting system worked as designed, triggered "on" by the loss of normal electrical power.

The passenger address (PA) system can be operated from the cockpit or the flight attendant handset, with power for the system supplied by the 28-volt dc battery bus. In this occurrence, the PA system became inoperable because electrical power was lost during the crash. There is no backup power for the PA system.

1.15.3 Air Canada Emergency Procedures

Whenever cabin crew suspect an impending impact--metal scrapes, unusual aircraft attitude, etc.--they must brace and command passengers to brace. In such situations, cabin crew are trained to react, whether or not they hear a signal to brace from flight crew. In life-threatening conditions, evacuations are initiated by the captain or any cabin crew member.

Air Canada's *Quick Reference Handbook (QRH*) contains checks that the flight crew must carry out, including a Severe Aircraft Damage and Land Evacuation check. Action items in this check that pertain to an evacuation are: emergency lights ON; order the evacuation, including appropriate instruction; and open exits and assist the evacuation. In this occurrence, the flight crew carried out their duties as indicated; however, the captain noted that the PA system did not work when he ordered the evacuation.

Air Canada has included a section on survival in the *Flight Attendant Manual,* Chapter 5, Emergency Procedures; one of the elements addressed is location. The section describes different approaches used by cabin crew to attract the attention of rescue personnel. Depending on the type of operation, cabin crew will have various tools and equipment available to them, such as beacon and strobe lights, whistles, flashlights, and hand-held flares. In this occurrence, flashlights were the only tools available to attract the attention of rescue personnel.

1.15.4 Training--Emergency Equipment and Procedures

CAR 705.124 (2) states, in part, that during initial and annual training, flight crew members are to receive emergency procedures training. Commercial Air Service Standards (CASS)

725.124 (14) states, in part, that practical training is required on the operation and use of emergency exits, and that the training shall be completed upon initial training and every three years thereafter.[13]

Air Canada advised that during initial emergency procedures and equipment training the practical training on the operation of emergency exits is conducted during line indoctrination. At that time, the pilots undergoing training operate only the passenger door and the galley service door. Neither the initial nor the transitional pilot training program of Air Canada includes practical operation of an over-wing exit or a flight deck escape hatch, both of which are emergency exits. During annual emergency procedures training, operation of emergency exits is reviewed by demonstration only. Initial training in relation to other emergency equipment, such as the crash axe, megaphones, and first aid kits, is taught using lectures and computer software programs. In addition, the pilots are shown all emergency equipment on board the aircraft just prior to their initial line indoctrination flight.

It was determined that neither the captain nor the first officer had received hands-on training on the operation and use of emergency exits, which includes the passenger door and galley service door, on the CL-65 aircraft. The captain had, by chance, once operated the passenger and galley doors of a CL-65 aircraft during a tour of the Bombardier facility. One of the flight crew had indicated on a written test that he knew there was a pry bar, which is standard emergency equipment, on the aircraft. At the time of the occurrence, neither flight crew member remembered or was aware that there was a pry bar on the aircraft.

Flight attendant training requirements are found in the CAR, CASS, and in particular in Transport Canada's Flight Attendant Training Standard TP12296. Emergency procedures training in relation to evacuations is required during initial, annual, and re-qualification training. Topics addressed include crew member responsibility, evacuation procedures, and post-evacuation procedures including signalling and recovery techniques. Appropriate emergency equipment training is required during both initial qualification and annual re-qualification. It is noted that Transport Canada does not require hands-on training for flight attendants on the operation and use of the flight deck escape hatch. The content and implementation of Air Canada's Flight Attendant Training Program meets regulatory requirements. The occurrence flight attendant was trained and qualified for the flight in accordance with existing requirements.

1.15.5 Occurrence Flight

The CL-65 met the emergency evacuation demonstration requirements of Transport Canada using no more than one flight attendant for the compliance test and met all other regulatory requirements for operation with one flight attendant. There was one flight attendant assigned to this flight.

The pre-flight passenger safety briefing and demonstration was given in accordance with Transport Canada requirements and Air Canada policy. The flight attendant provided individual briefings to two men seated in the over-wing exit row. One of the men interviewed following the occurrence stated that although he often sits at an over-wing exit when he flies, this was the most thorough briefing he had ever received. He noted that the flight attendant not only described the operation in detail but demonstrated how to remove the plastic cover over the exit handle. The flight attendant advised that when he gives an over-wing exit briefing, he speaks loudly enough so that other passengers sitting in the area will also hear the briefing.

The passenger at 1E, travelling with an infant, had brought the infant on board in an approved child restraint device. The adjacent seat, 1C, was not occupied; however, she was unable to use the device as it would not fit between the armrests on the seat. The child restraint system was moved to the baggage area. It should be noted that there was very little carry-on-baggage in the cabin, as Flight ACA646 encouraged passengers to use the Sky Check service.[(14)]

When the aircraft initially struck the runway, the flight attendant immediately assumed his brace position and began shouting commands to the passengers: "Emergency. Bend over. Grab your ankles. Keep your head down." Interviews with passengers indicated that some heard the flight attendant's shouted commands, while others did not. There did not appear to be a relationship between passenger seat location and hearing the flight attendant.

When the aircraft came to a stop, the captain made an announcement on the PA system: "Evacuate. Evacuate." but because there was no electrical power the announcement was not heard. At the same time, the flight attendant undid his restraint system and made a rapid assessment of the situation. Given the obvious requirement to evacuate, he did not wait for the captain's command but immediately initiated an evacuation. The passengers responded quickly and calmly. The flight crew completed their respective duties and entered the cabin to assist with the evacuation. Two passengers, one with an infant, are known to have evacuated via the passenger door opening. Approximately 17 passengers exited through the right over-wing exit, and 12 through the left.

The flight attendant shouted to passengers outside the aircraft to "get away from the aircraft," and "stay together." After he completed a cabin check to ensure that all passengers, except those who were trapped, had evacuated, he left the aircraft via the right over-wing exit. The flight attendant saw runway and vehicle lights and heard sirens. He used his flashlight to signal rescue personnel but received no response. He gave his flashlight to a passenger, with instructions to continue signalling, and re-entered the aircraft.

The three crew members and some passengers who had re-entered the aircraft worked together to extricate the trapped passengers, but were not successful. At one point, the flight crew used the handle of the crash axe in an unsuccessful attempt to pry free a passenger's hand trapped between the fuselage and a seat; the axe handle bent. Neither flight crew member was aware that a pry bar was standard emergency equipment on the aircraft.

The flight attendant who was travelling as a passenger exited out the right side of the aircraft and quickly assumed a leadership role. She assembled the passengers around her in a group and had them "sound-off" to establish a passenger count. This process was repeated periodically to confirm that no one had wandered away. She stopped passengers from

re-entering the aircraft while the engines were running and, given the strong smell of fuel, warned them not to smoke or light matches. When the engines stopped, she boarded the aircraft and gathered up coats for the passengers outside.

Later, as rescue personnel had not arrived, the occurrence flight attendant again exited the aircraft and instructed some passengers to take the flashlight and make their way to the runway. Most passengers made their way in small groups, some passengers without winter clothing or footwear. They shouted for help as they went, but rescue personnel could neither see nor hear them. As they reached the edge of the runway, they met rescue personnel who took them to the terminal, from which they were transported to hospital. The three crew members stayed on the aircraft with the trapped passengers until rescue personnel arrived.

Passengers who exited on the left side were surrounded by forest. Because the left engine was running and there was a strong smell of fuel, the passengers moved away from the aircraft. They walked deeper into the forest, eventually making their way through the trees to the right side of the aircraft where there was a clearing and a route to the runway.

1.15.6 Emergency Response

CAR, Part III - Aerodromes and Airports, 323 - Aerodrome and Airport Standards Respecting Aircraft Fire Fighting at Airports and Aerodromes, 323.03 General Requirements, states the following:

The principal objective in providing an aircraft fire-fighting service is to save lives in the event of an aircraft emergency on the airport or aerodrome. In this context, an aircraft fire-fighting service is a contingent resource tasked with the primary responsibility of providing a fire free egress route for the evacuation of passengers and crew following an aircraft accident.

At about 2348, the FSS specialist heard the aircraft go by, but he did not see it and did not know if it had landed. At 2350:27, after an unsuccessful radio search for ACA 646, the specialist dispatched the one firefighter who was on duty to the runway to search for the aircraft; he used the primary airport emergency response vehicle, callsign Red 3; the second firefighter had left work at 2330 because of illness. The airport maintenance foreman, who was listening to the radios, also joined in the search. The drivers searched unsuccessfully for the aircraft and for tracks the length of runway 15/33, off each side and each end, having to travel at slow speed because of the reduced visibility in dense fog. At 2358, with no sign of the aircraft, the specialist commenced a call-out in accordance with the emergency response plan. He first placed a call to the 911 operator and requested that the Fredericton hospital (D.E.C.H.) be advised that there may have been a crash of an aircraft on or near the airport. After that call the specialist called key personnel listed on the Fredericton Airport Emergency Response Plan checklist. At about 0002:30, about 14 minutes after the crash, a driver spotted someone walking toward the runway and determined from him that he was a passenger, and that the aircraft had crashed and was west of the runway. This information was passed to Red 3 and the FSS specialist.

When the firefighter arrived at the field maintenance worker's location, he and an RCMP officer, who had arrived in the meantime, started to walk to the site. At approximately 0006 they met a group of 15 to 20 passengers walking toward them, led by the off-duty flight attendant. The firefighter pointed them in the direction of the runway and advised them there was a field maintenance worker there. They next met a woman carrying an infant. The RCMP officer escorted the woman to the edge of the runway, while the firefighter continued on until he found the aircraft. When he arrived, the only people still on board were the three crew members and the seven trapped passengers. He could smell fuel, but the engines were off. He reported to the FSS specialist an estimated position of the aircraft.

In the meantime, the field maintenance worker requested another worker drive out to the intersection of runways 15 and 09 with a van to transport some of the passengers. He himself took two passengers to the terminal building and dropped them off there, with instructions to go inside the building and remain there. A second airport firefighter arrived at the airport and took the Rapid Intervention Vehicle out to the runway to assist the firefighter from Red 3. The two firefighters discussed the requirement to extend a handline [fire hose] from a fire truck to the aircraft because of the leaking fuel. They tried to drive the Rapid Intervention Vehicle through the snow, but, as it was not designed to travel off roads in deep snow, it became stuck after driving only a few feet. Additional firefighting, ambulance, and police personnel from Fredericton, Oromocto, and Canadian Forces Base (CFB) Gagetown arrived at the airport between 0010 and 0020, and were guided to the intersection of the two main runways.

The field maintenance foreman dispatched a snowblower to the intersection of the two runways, as he knew that a road would have to be cut through the snow to the aircraft. The snowblower immediately started clearing a path toward the aircraft from the intersection of runway 15 and 09, following the wreckage trail. An airport worker had to walk in front of the snowblower to make sure no pieces of wreckage were ingested and to watch out for any more passengers walking out. On reaching the drainage ditch which runs parallel to runway 15 east of runway 09, they had to back up and clear a different path. The new path followed a road from the intersection to the bottom of the hill on which the aircraft was sitting.

With the clearing of a road to the aircraft, at 0038, police vehicles and ambulances were able to drive out to the accident site. Red 3 and the two airport firefighters also drove out to the site, and they were able to run a fire hose from Red 3 to the aircraft. A portable jaws-of-life from the CFB Gagetown fire department was used to assist in the extraction of the trapped passengers. Other key personnel had arrived at the airport, including the Fire Chief, Airport manager, and Airport Operations Manager. The Emergency Communications Centre was opened at 0054.

The last trapped passenger was removed from the aircraft at 0234, two hours and 46 minutes after the crash. A ground search was initiated at 0213 for two unaccounted for passengers. They were subsequently located at 0443; these passengers had left the terminal building with family members and had gone home.

1.15.7 Emergency Locator Transmitter

Under CAR 605.38, multi-engine turbo-jet aeroplanes of more than 5700 kg maximum certified take-off weight, such as the CL-65, are not required to be equipped with an emergency locator transmitter (ELT) when operating in IFR flight within controlled airspace over land and south of latitude 6630' North. Non-turbo-jet aeroplanes, like the Dash-8 and ATR-42, similar to the CL-65 in terms of passenger capacity and operational environment, are required by regulations to be equipped with an ELT. The occurrence aircraft was not equipped with an ELT.

TSB information indicates that there is no significant difference in accident rates between turbo-jet and non-turbo-jet aeroplanes strictly as a function of propulsion system factors.

The Fredericton FSS specialist heard the aircraft go by; however, he did not see it because of the limited visibility. FSS specialists routinely monitor the emergency frequency, 121.5 MHz; the emitting frequency of ELTs is 121.5 MHz or 243 MHz. On hearing an ELT signal that is not a test, the specialist will notify the ACC, and then follow written procedures to attempt to locate the source. FSS specialists located at airports have access to portable ELT detectors, and there was one at Fredericton; however, an FSS specialist is not to leave an FSS position unattended to conduct a search for an emitting ELT. In such a situation, the detector can be used by some designated person to conduct the search. Local training on the use of detectors is provided to FSS specialists, and written instructions for the operation of the detectors are available.

1.16 Tests and Research

Tests and research were conducted to assess aircraft performance. Details of these tests are contained in the Performance Section of this report, Section 1.18.3, and in the Performance Group Report, as follows:

- Bombardier FS/97/601R/040/AK--Flight Simulation Investigation of the Canadair Regional Jet Accident (30 April 1998).

- Bombardier AA/98-7/FT--Ice Accretion Study (4 March 1998).

- Bombardier AA/98-40/FT--Aerodynamic Degradation due to Surface Pitting (29 May 1998).

- Bombardier FS/98/601R/056/SN--Effect of Protruding Sealant on the RJ (7 August 1998).

- Institute of Aviation Research (IAR) Report LTR-A-023--Review of Surface Contamination Analysis Tools (May 1998).

- IAR Report LTR-A-025 - Ice Accretion Analysis (May 1998).

- IAR Ice Sublimation Study letter (19 June 1998).

- IAR Report - FDR Data Quality Analysis and Performance Evaluation.

- IAR Report - The Effect of Ground Proximity on Aircraft Performance (September 1998).

- Quality Engineering Test Establishment (QETE) 10081-H028297--Analysis of Sealant Material (20 March 1998).

- Rosemount Aerospace Document D9820221--Ice Detector Response Time (17 April 1998).

1.17 Organizational and Management Information

1.17.1 Air Canada Regional Jet Training Program

1.17.1.1 Introduction

The information in the following subparagraphs is based on the training program that was in effect at the time of the occurrence, and at the time that the captain received captain upgrade training and the first officer received initial CL-65 training.

1.17.1.2 Pilot Training

New-hire pilot candidates first complete a 12-day initial course covering the Air Canada Publication 550, *Flight Operations Manual (FOM)*--the equivalent of the Company Operations Manual required by the CAR--and CRM training. New-hire pilots and pilots who transition from other Air Canada aircraft then complete a standard course on the applicable aircraft. During ground training, first officer and captain candidates receive two weeks of training covering the aircraft and its systems. They complete nine 2-hour sessions in the fixed training device and then nine sessions in a full flight simulator with an instructor. All candidates receive training on aircraft performance, and pilots without jet aircraft experience receive appropriate instruction pertaining to aerodynamic characteristics of swept-wing jet aircraft. During the last session, all pilots are required to take the Transport Canada Pilot Proficiency Check and Instrument Flight Test

(PPC/IFT) check-ride, conducted by either a Transport Canada inspector or a Transport Canada-designated Air Canada company check pilot.

Airborne training follows the PPC/IFT check-ride and consists of a one-hour flight during which candidates conduct circuit work to achieve pilot proficiency to a satisfactory standard. During this training, candidates are required to pass an airborne PPC. Pilots then complete a minimum of two familiarization flights in the jump seat of a revenue flight.

1.17.1.3 Line Indoctrination and Command Training

Following the training period, all candidates fly a minimum of 25 hours of line indoctrination with a flight instructor or line indoctrination captain. This allows both first officer and captain candidates to develop greater familiarity with the aircraft and some of the route structures of the CL-65. Captain candidates become familiar with the communication requirements of a captain and gain confidence in the role of captain.

Following successful check-rides at the end of the line indoctrination training, first officers are released to the line for normal flying. Captain candidates are required to then complete the Air Canada Command Training Program, pass a command initial line check to establish competency in the left seat, and complete command indoctrination. The command indoctrination comprises a minimum of 50 hours of left-seat line flying accompanied by a qualified captain, and two 4-hour simulator sessions. Throughout this stage, captain candidates remain qualified as first officers, although they perform as captains. They are required to make all decisions and perform all functions as if they were captain on the aircraft, with intervention by a supervising pilot when necessary for safety and operational reasons. The final stage of the command training program is the command final line check. At this stage, an Air Canada check pilot assesses a candidate's performance as captain during line operations, the final determining factor for a candidate's progression to the left seat. Typically, a pilot will take two to three months to complete the captain's course.

1.17.2 Crew Pairing

CAR 705.106 (1 and 4), Pilot Qualifications, and CAR 725.108, Crew Pairing, outline requirements regarding flight crew qualifications and considerations for crew pairing. The Air Canada *FOM* reiterates the requirements of the CARs and related standards and does not contain additional crew-pairing restrictions. Neither the captain nor the first officer was subject to crew-pairing restriction: the captain of the occurrence aircraft had been qualified as captain on type for 14 months; and, by the date of the occurrence flight, the first officer had acquired over 60 hours in the 25 days since he began flying the CL-65.

1.18 Other Information

1.18.1 Conduct of the Flight

1.18.1.1 General

As the flight neared Fredericton, the crew briefed for the ILS approach to runway 15 and reviewed the missed-approach procedures. Their intent was to conduct up to two approaches to Fredericton and then, if weather at Fredericton precluded landing, proceed to Saint John as the alternate. They received appropriate missed-approach instructions from ATC.

1.18.1.2 Assignment of Flying Duties

It is normal in most airlines, including Air Canada, for captains and first officers to alternate pilot-flying (PF) and pilot-not-flying (PNF) duties. The first officer was performing the PF duties for the Toronto-Fredericton leg, and the captain the PNF duties. Because of the low-weather conditions reported at Fredericton, the crew discussed the first officer's experience in 1200-RVR conditions. Although the first officer had not flown approaches on the CL-65 when the RVR was 1200 feet, he had flown a number of them on other aircraft. Following the discussion, the captain decided to continue with the existing allotment of flying duties, with the first officer flying the approach. This crew had flown together on this date only and had completed two legs. On these two legs and during the Toronto-Fredericton leg the captain had found the first officer to be a competent pilot.

The *FOM*, Chapter 4, Section 13.04, in part provides the following guidance for Category I, low-visibility approaches:

It is recommended that the captain fly the approach when the RVR is less than the charted landing visibility for the approach, except when the approach is made to a runway with operative high-intensity approach lighting (HIAL), touchdown zone lighting (TDZL), and centre-line lighting (CLL).

Runway 15 at Fredericton is not equipped with touchdown-zone lighting or centre line lighting.

Transport Canada conducted a Special Purpose Audit after the occurrence to review Air Canada's CL-65 operations. It was noted by the auditors that Air Canada senior pilots agree that Section 13.04 of the *FOM* reflects Air Canada's confidence in the judgement of its captains, and that it would be detrimental to the development of first officers if they were never permitted to fly such approaches.

ILS category I approaches are flown by any instrument-rated pilot as a means of achieving visual contact with the landing area and, as such, there are no special requirements stipulated in regulations or company procedures regarding these approaches. Even though a Category I approach may be conducted in weather conditions lower than the minimuma specified for the approach, there is no special training required by Transport Canada for any flight crew member, nor is there a requirement that flight crew be tested on their ability to fly in such conditions.

1.18.1.3 Final Approach to Go-around Command

The crew were provided with radar vectors to intercept the ILS localiser and cleared for the

ILS-15 approach to Fredericton Airport. The landing minima for ILS-15 were visibility of ½ mile or RVR 2600 feet, and decision height of 264 feet asl, 200 feet above the touch-down zone height of 64 feet asl. The minimum RVR required to commence the approach to land was 1200 feet.

There were no anomalies noted with the descent from altitude, except that the auxiliary power unit (APU) PWR/FUEL switch was selected ON, but the APU was not started; this had no effect on the flight. The aircraft arrived at decision height in the landing configuration (landing gear down, flaps 45), three knots below the target airspeed of 144 KIAS (V_{REF} + 5 knots), on glide path, and tracking slightly right of the localizer with about 5 degrees of right crab.[(15)] At decision height the captain called the lights in sight. The first officer looked up and saw approach and runway-end lights and, based on these visual references, made the decision to land.

Air Canada procedures for Category I approaches stipulate that once a decision to land is made, the PF will continue using outside references to maintain the aircraft on the slope and runway centre line and complete the landing. The PNF is expected to monitor the outside visual cues and the instrument indications in the cockpit, and notify the PF of significant deviations from the intended flight path.

Air Canada recommends that the autopilot be used when conducting approaches in low-visibility conditions; however, there is no guidance as to when the autopilot might be disconnected during the approach. The *AFM* states that the minimum altitude for disconnecting the autopilot is 80 feet.

After the first officer confirmed that he would be landing, he disconnected the autopilot. FDR data indicate that subsequent to the autopilot being disconnected the pitch of the aircraft increased, the descent rate reduced, and the aircraft went above the glide path; the captain prompted the first officer to keep it down. Following this prompt the thrust was reduced, the pitch attitude was lowered momentarily, but again increased, and the aircraft rolled to about five degrees of left bank as a result of left rudder and left aileron inputs; the captain again prompted the first officer to keep the nose down. Two seconds later, the aircraft was at 60 feet above the runway, still banked to the left, and drifting left through the localizer. When the first officer realised that the aircraft was drifting left, he attempted to make corrections but only arrested the drift when the aircraft was left of the centre line. At about 33 feet above the runway, with the aircraft about 50 feet left of the runway centre line and about 1300 feet down the runway, the captain ordered a go-around. The aircraft was three knots below the target speed of 144 knots at decision height and, at the threshold, where, according to the *AFM*, the speed should have been V_{REF} (139), it was 144 knots. The speed reached 139 knots at about 50 feet agl, about four seconds after crossing the threshold.

Through the ground proximity warning system, the RADALT automatically verbalizes "fifty," "thirty," and "ten," indicating the aircraft height, in feet, above the runway during landing. Neither pilot remembers hearing the calls, and the captain thought that the aircraft had not yet reached 50 feet when the go-around was ordered. The 50-foot call was during the five-second period between the captain's second prompt and the go-around command, the 30-foot call was between the captain's go-around command and the first officer's acknowledgement, and the10-foot call was one second after the stick shaker started.

The following table summarizes data derived from the flight recorders for this phase of the flight:

Time (0347:)	Event	ALT	VS	IAS	AS	N_1%	P
11.4	Captain calls minimums and lights	201	-700	141	0.0	68	-2.0
14.8	First officer calls landing	166	-800	143	1.4	68.3	-2.2
15	Autopilot disconnected	165	-800	143	1.2	68.3	-2.2
19.4	Captain prompts FO to keep it down	132	-500	145	0.3	68.5	-0.9
22.5	Pitch adjusted (0347:21-0347:23)	96	-450	145	0.3	68.4	-1.1
24	Engine N_1 starts to decrease to idle	79	-400	145	-0.7	64.7	-0.6
25.1	Runway threshold crossing	72	-400	144	-1.0	58.8	-0.5
25.9	Captain prompts FO to keep it down	68	-300	143	-1.4	53.6	-0.1
29.2	RADALT - "Fifty" feet	49	-500	138	-1.9	36.4	-1.5
30.9	Captain commands the go-around	33	-600	135	-2.0	29.4	-1.0

ALT Radio altimeter altitude

VS Derived vertical speed (feet per minute)

IAS Indicated air speed

AS Airspeed change per second

N_1% Left engine N_1 speed

P Pitch attitude

Many CL-65 pilots stated that on final approach the CL-65 is in a nose-low attitude because of its fairly high approach speed. It is recognized that the combination of low pitch attitude, high approach speed, darkness, and low visibility may result in a sensation that the aircraft is approaching the ground too fast, which would result in a tendency to raise the nose and to round out the aircraft earlier than required. This tendency is particularly pronounced when first transitioning to the CL-65 both from slower, more conventional aircraft and from larger aircraft with a higher pilot eye-reference point. In addition, because the engines are above the C of G, there is a tendency for the CL-65 aircraft to pitch up when thrust is reduced. These illusions and aerodynamic tendencies have been recognized and are discussed during pilot training. Both the captain and the first officer were aware of these characteristics.

1.18.1.4 The Go-around

Go-around Certification

There are a number of terms used to describe the various phases of flight during the final approach and landing of transport category aircraft, and there is some inconsistency in how these terms are used. The term "go-around" is used in a variety of ways by regulators, manufacturers, and operators to describe a procedure where an aircraft discontinues either an approach, or a transition to visual flight for landing, or a landing, and then climbs away. The implications of this variation are significant, as these procedures are not identical. Below is a description of each phase and the associated major considerations for a go-around in each phase. The definitions here are to provide a standard for discussions within this report and are not necessarily related to aircraft certification.

Go-around--the act of terminating an approach to land, for whatever reason, and climbing away.

Missed Approach--termination of an instrument approach at or above the minimum descent altitude (MDA) or decision height. Normally, at the start of the missed approach, the aircraft would be on the desired flight path, configured with the landing gear down and the flaps as required for the type of approach, and with the power and speed stabilized. A missed approach could be required because of the inability of the crew to see enough of the runway environment to land, or because the aircraft was not in a position to land safely.

Rejected Landing--termination of the approach to land after the decision to land has been made by the crew. Normally, at the start of the rejected landing, the aircraft would be on the desired flight path, configured with the landing gear down and the flaps in the land position, and with the power and speed stabilized. A rejected landing could be required because the crew's view of the runway environment was lost or there was some obstruction on the runway. The term rejected landing is not used in the context of aircraft certification, but it is a common term in the aviation community.

Rejected Landing with Power at Idle--a go-around from a missed approach or rejected landing is started with the engine(s) at approach power. However, there will be times when a go-around is required, or deemed to be required, after the power has been reduced to idle for landing. This is the area of the approach to land where the crew of Flight ACA646 found themselves. There are no Canadian or American certification requirements related to a rejected landing with the power at idle, Transport Canada does not require manufacturers or operators to discuss the subject in applicable manuals, and pilots are not required to train for such a manoeuvre.

Balked Landing--a balked landing is a type certification manoeuvre, and refers to the all-engine go-around from V_{REF} in the landing configuration, as described above for a rejected landing. This term is rarely seen in AFMs or other manuals used by operators and pilots. For operator manuals, aircraft type ratings, and proficiency checks, the term rejected landing is normally used.

Certification standards contained in Special Federal Aviation Regulation, Title 14, Part 25, Airworthiness Standards, Transport Category Airplanes, Sec. 25.101(g), require that procedures for the execution of balked (rejected) landings and missed approaches associated with the conditions prescribed in Sections 25.119 (Landing Climb) and 25.121(d) (Approach Climb) be established by the manufacturer. According to Transport Canada, demonstrations of balked landings and missed approaches during certification are initiated from a stabilized descent at V_{REF} or, for approaches in which one engine is inoperative, at V_{APP}. The initial thrust setting is the one appropriate for the stabilized approach at a nominal glide path of three degrees. Due to the special circumstances surrounding Category II approaches, the manufacturer is also required to demonstrate acceptable altitude losses during one-engine go-arounds from 100 feet.

The expectations of Transport Canada and Bombardier Inc. were that a go-around in the CL-65 would be initiated from within the demonstrated flight envelope for a go-around: landing gear and flap down, at the appropriate reference speed, at a normal approach rate of descent,[(16)] and with approach thrust applied.[(17)] It was anticipated that once the thrust levers were advanced and the flaps started to rise, the engine thrust would increase rapidly and become sufficient to increase the airspeed while the pitch attitude was raised to the flight director command bars.

According to information provided by Transport Canada after the accident, a go-around or balked landing outside the demonstrated flight envelope is a high-risk manoeuvre. If a

go-around is attempted from a low-energy state, such as after the thrust levers are reduced for landing, ground contact is likely, and any attempt to commence a climb before the engines have achieved go-around thrust could result in a stall. This is primarily because of the time required for the engines to spool up to go-around thrust--about eight seconds.

During certification of an aircraft, manufacturers are required to demonstrate go-arounds; however, the conditions under which the go-arounds are demonstrated do not form part of the documentation that leads to aircraft limitations or boundaries for the go-around procedure. Even though the conditions of the go-around may not lead to limitations, the information could be of use to pilots. The only published restriction to conducting a go-around in a CL-65 is contained in a CAUTION in the *AFM* (See the next section, Go-around Procedures), which states that a go-around manoeuvre should not be attempted after the thrust reversers have been deployed.

Go-around Procedures

The *FOM*, Chapter 5, Section 5.08, states that "a missed approach shall be initiated when, in the opinion of the pilot-in-command, a safe landing cannot be accomplished within the touch-down zone and the aircraft stopped within the confines of the computed stopping distance."

The *AFM*, CSP A-012, Normal Procedures, page 04-20-17, Rev 50, Jun 01/97, contains the following:

The following procedures are recommended in the event of a missed approach or any other situation which would necessitate making a go-around manoeuvre, with the airplane in the landing configuration [gear down, flaps 45]:

CAUTION

A go-around manoeuvre should NOT be attempted after the thrust reversers have been deployed.

(1) Thrust levers/Go-around switch: Advance the thrust levers to normal take-off N_1 thrust setting while pressing the TOGA (take-off and go-around) switch.

(2) Airplane: Rotate smoothly towards the target pitch attitude of +10 to arrest descent.

(3) Flaps: Select to 8.

(4) Pitch attitude: Adjust to achieve an airspeed of not less than $V_{2(\text{Flaps 8})}$ +10 as the flaps are retracted to 8.

When a positive rate of climb is achieved:

(5) Landing gear: Retract.

(6) Airspeed: Maintain not less than $V_{2(Flaps\ 8)}$ +10 KIAS.

(7) Normal climb out procedures: Accomplish.

Air Canada's *CL-65 Airplane Operating Manual* (*AOM*), page 02.37.02, Sep 17/97, contains the following:

TWO-ENGINE GO-AROUND

PF calls "GO-AROUND, FLAPS" while simultaneously applying go-around thrust, pressing the go-around button on the thrust lever and smoothly rotating towards the flight director target attitude [+10] to achieve a speed not less than V_2 +10. The PNF selects flaps to the gate position (i.e., Flap 8), and confirms thrust is correctly set.

When in a stabilized climb, PNF calls "POSITIVE RATE". PF then calls "GEAR UP".

The following graphic outlines the two-engine go-around procedures (as depicted in the *AOM*, page 02.37.02).

The Air Canada *Flight Crew Training Manual* (Publication 595), Student Study Guide, Chapter 4/3, Page 16, Date 96 10 24, contains the following:

GO-AROUND TECHNIQUE

2 Engine - Procedures will be followed as outlined in the *AOM* 02.37.02.

- PF will call "Go-around, Flaps" while applying go-around thrust and pressing the go-around button on the thrust levers. Rotation will be made smoothly towards the flight director pitch guidance to arrest the descent. When the FMA [flight mode annunciator] indicates G/A [go-around] mode, the flight director pitch attitude should be used only as an initial guidance to establish a positive vertical speed.

Afterwards, indicated airspeed, in conjunction with other vertical flight instruments is used for pitch control to achieve a minimum speed of V_2 +10. Coarse or rapid pitch up inputs may result in activation of the stick shaker.

There is no reference to rejected landings in the *AFM,* the *Flight Crew Operating Manual (FCOM)*, Volume 2, or the *AOM*. The only reference to a rejected landing procedure for the CL-65 was found in the Air Canada *Flight Crew Training Manual*, Airborne Flight Training, Chapter 5, Page 10, Date 96 10 26, which states in part:

REJECTED LANDING

- The rejected landing should not be done below 50 feet.[(18)] It is similar to the normal go-around in that TOGA switches are activated simultaneously with the advancement of the thrust levers. Pitch up must be positive to the command bars or 10 degrees.

AIRSPEED IS THE PRIMARY CONSIDERATION

A number of other sections in the Air Canada *Flight Crew Training Manual* related to two-engine go-arounds stress that:

The F/D target <u>pitch attitude</u> should be used as <u>initial guidance ONLY</u>.

After positive pitch is obtained/maintained, indicated airspeed (SPEED mode) and vertical speed are the primary indicators for pitch control.

The most common error for go-arounds is cited as "Not rotating to the F/D."

On 21 August 1996 a Transport Canada inspector provided a report to Air Canada containing his evaluation of simulator situations wherein CL-65 crews were experiencing significant speed losses and in some cases stick shaker activation during single-engine go-around procedures. Extensive testing and analysis indicated that the simulator was true to the aircraft performance, and that the undesirable symptoms experienced were the result of pilot technique and training. In particular, his report indicated that pitch-up rates and flap retraction delays played a vital part in the airspeed losses encountered. In response to this information, Air Canada reviewed the following publications: the *AFM*, the *FCOM*, the *AOM*, and the *Flight Crew Training Manual*. The manuals were revised, in part, to emphasize that the flight director guidance is an initial reference to arrest descent. Other Transport Canada documentation indicates that subsequent revisions to the *AFM* and the *FCOM* were made in 1996 to promote more awareness of airspeed during the go-around.

There is no guidance found in the *AFM*, the *FCOM*, the *AOM*, or the *FOM* on cockpit coordination procedures in situations when the captain, as the PNF, commands a go-around.

Go-around Training

Go-around flight training for Air Canada pilots is conducted in the flight simulator. Training

go-arounds are routinely practised from the decision height or missed-approach point of the instrument approach, with the aircraft in the landing configuration, at the appropriate referenced speed, at the normal approach rate of descent, and with the engines producing approach thrust. Occasionally, go-arounds (rejected landings) are conducted from altitudes below the instrument MDA in reaction to a simulated, unexpected obstruction to the runway. For these simulations, the go-arounds are normally conducted from the normal approach profile, configuration and thrust settings, and prior to the final thrust reduction for landing. The training program at the time of the occurrence did not include go-arounds/rejected landings from low-energy states, such as that encountered on the occurrence flight, and Transport Canada did not require pilots to demonstrate proficiency in this area.

Occurrence Go-around

When the captain ordered the go-around, the first officer acknowledged the order, started to advance the thrust levers, selected the go-around mode for the flight director, and started to increase the pitch of the aircraft toward the command bar indication. When he felt the captain advancing the thrust levers, the first officer took his hands off the thrust levers. Normally, the PF would quickly set approximate go-around thrust, and the PNF would adjust as necessary to obtain the correct setting. About one second after the first officer acknowledged the go-around, the stick shaker activated; one and a half seconds after the stick shaker activated, the captain called and selected the flaps to the go-around setting. At the same time that the captain selected the flaps, the warbler tone sounded and the aircraft started to roll to the right.

The following table depicts the recorded data for the occurrence go-around.

Time (0347:)	Event	ALT	VS	IAS	AS	N_1%	P
30.9	Captain commands the go-around	33	-600	135	-2.0	29.4	-1.0
31.5	RADALT - "Thirty" feet	27	-600	134	-2.3	27.8	0.5
31.9	First Officer acknowledges go-around	23	-600	133	-2.5	26.9	1.3
33.1	Stick shaker activates	14	-350	129	-2.9	27.0	4.0
34.1	RADALT - "Ten" feet	11	-100	126	-3.5	30.5	7.8
34.7	Stall onset / right roll starts	14	300	124	-3.9	34.7	9.6
34.8	Captain calls flaps / Warbler tone activates	13	400	124	-3.6	35.4	9.7
36.3	Peak altitude	32	0	121	-2.8	59.0	3.2

ALT Radio altimeter altitude

VS Derived vertical speed (feet per minute)

IAS Indicated air speed

AS Airspeed change per second

N_1% Left engine N_1 speed

When he ordered the go-around, the captain estimated that the aircraft had travelled about

1000 feet past the threshold and was above 50 feet agl because he had not heard the RADALT call. From the FDR data it was determined that when the go-around was ordered the aircraft was at 33 feet, 135 knots, and approximately 1300 feet past the approach end of the runway. The first officer was not surprised by the captain's go-around call because he was just about to make the same call.

When the go-around was called, the first officer transitioned his attention to the instruments inside the cockpit, and the captain does not recall looking outside after ordering the go-around. The first indication to the crew that something was amiss was the activation of the stick shaker. During the 1.2 seconds between the first officer's acknowledgement of the go-around call and the stick shaker activation, the first officer was concentrating on achieving the target pitch attitude, and the captain was occupied with the PNF duties of setting the go-around thrust setting and ensuring proper aircraft configuration.

Go-around Energy State

Thrust lever position is not recorded on the FDR, so Bombardier Inc. was asked to provide an analysis of the available engine data from the FDR to determine thrust lever movement during the go-around. The conclusion of this analysis was that, from the point of the go-around command acknowledgement by the first officer, the engines accelerated at a rate expected for a power slam (power lever movement faster than engine acceleration, with the engine accelerating at its maximum rate).

Bombardier Inc. also provided the following conclusions based on their analysis of the FDR information.

Significant aircraft energy-state conditions at the time that the go-around was initiated as compared to the conditions expected for the manoeuvre are as follows:

1. The airspeed was six knots below the V_{REF} speed of 139.

2. The engine N_1 speed was 29%, 39% below the nominal approach thrust setting of 68%.

3. The engine N_1 speeds reached 68%, a nominal approach thrust setting, five seconds after the go-around acknowledgement.

4. From the time of the go-around acknowledgement, the engines reached 92%(19) N_1 in 7.5 seconds; from a nominal approach thrust setting, go-around thrust would normally be reached in three seconds or less.

5. The flaps started to rise three seconds after the go-around acknowledgement; flaps are normally selected and moving within a second of the go-around call.

6. The airspeed decreased at a rate of about three knots per second throughout the manoeuvre; airspeed would normally increase during the procedure

[go-around].

1.18.1.5 Stall Prevention

Stall Recovery Procedures

The *AOM*, Volume 2, pages 03.03.10 and .11, contains stall recovery procedures. It is stated that the CL-65 exhibits stable flight characteristics approaching the stall, while responding positively in all axes. Stall recovery procedures are described as follows:

RECOVERY - GROUND CONTACT NOT A FACTOR

at first indication of stick shaker:

- -Thrust Levers MAXIMUM THRUST
- -Autopilot DISCONNECT

- -Pitch MAINTAIN
- -Wings LEVEL

As speed increases, adjust pitch to minimize altitude loss.

Maintain existing configuration until positive rate.

RECOVERY - GROUND CONTACT A FACTOR

at first indication of stick shaker:

- -Thrust Levers FIREWALL [Push thrust levers fully forward]

The remaining actions are the same as ground contact not a factor.

In the crew coordination chart following the GROUND CONTACT A FACTOR check, there is, for the PF, "Respect stick shaker". This is understood by CL-65 pilots to mean flying the aircraft at a speed/attitude just outside of stick shaker activation.

The *Flight Crew Training Manual*, Chapter 3.5, page 10, contains procedures for stall recovery:

GROUND CONTACT A FACTOR

At the first indication of stall, the activation of the stick shaker, the thrust levers are immediately advanced to the maximum thrust and at the same time, the aircraft pitch attitude is smoothly and slightly reduced to stop the stick shaker . . . .

The *Flight Crew Training Manual*, Chapter 4/4, pp. 8-9, contains stall-recovery training procedures for the CL-65; the training is done in the flight simulator. Landing-configuration stall recovery training is done in level flight at 9500 feet, with engine N_1 thrust set at 45%, and increasing back pressure to the stick shaker. The recovery is done as per the *AOM*, with flaps and landing gear left down until the aircraft achieves a positive rate of climb. Additionally, it is stated that "it is very important that the PNF provide verbal cues as to the aircraft's flight path conditions **emphasising airspeed & sink rate** (increasing/decreasing) and **altitude** when ground contact is a factor." (Emphasis in original text.)

Transport Canada records indicate that, for the CL-65, pusher activation results in a strong nose-down pitch that can not be readily arrested with normal pilot effort. With flaps 45 and landing gear down, the aircraft typically pitches down by a maximum 20 to 30 degrees in five seconds. The height loss depends on the recovery procedure but is in the order of 1000 feet.

Occurrence Flight--Stall

The following table depicts recorded data associated with the aircraft stall:

Time (0347:)	Event	ElevL	ElevR	Roll	ALT	IAS	P
30.9	Captain commands the go-around	-5.6	-7.7	-0.4	33	135	-1.0
31.5	RADALT - "Thirty" feet	-4.5	-4.5	0.3	27	134	0.5
31.9	First Officer acknowledges go-around	-3.8	-4.3	1.3	23	133	1.3
33.1	Stick shaker activates	-11.5	-13.8	3.8	14	129	4.0
34.1	RADALT - "Ten" feet	-8.1	-7.5	1.6	11	126	7.8
34.7	Stall onset / right roll starts	-2.3	-3.7	4.4	14	124	9.6
34.8	Captain calls flaps / Warbler tone activates	-2.6	-3.8	5.4	13	124	9.7
36.3	Peak altitude	-2.0	-2.0	54.3	32	121	3.2

ElevL Left elevator position

ElevR Right elevator position

Roll Positive values for right bank

ALT Radio altimeter altitude

IAS Indicated air speed

P Pitch attitude

After the shaker activated, the control column was moved slightly forward, perhaps in reaction to the shaker or to stop the aircraft pitch at 10 degrees; however, as shown above, the pitch attitude continued to increase even though the elevator deflection decreased. The captain indicated that the time between the initial shaker and the first contact with the runway was so short that he did not have time to take any action in response to the shaker. FDR data indicate that about five seconds after the stall, the left and right engines achieved maximum N_1 speeds of 94.0% and 92.2%, which is somewhat above the 86% range specified for the go-around/take-off thrust levels for the existing environmental conditions.

1.18.1.6 Runway Length

Calculations by the Air Canada dispatcher responsible for the flight showed that the required runway length for landing at Fredericton, assuming a landing weight of 20 000 kg and a wet runway,[(20)] was 5400 feet, which was in accordance with the performance landing data on page 04.80.03 of the *AOM*. The dry runway landing distance required would have been 4700 feet. The landing distance available on runway 15 at Fredericton was 6000 feet.

According to the *AOM*, the actual dry landing distance for the estimated landing weight of 20 200 kg would have been 2842 feet. The dry landing distance required by the *AOM* is calculated by multiplying the actual dry landing distance by 1.67, in this case, equalling

4746 feet. The required wet runway distance is 1.15 times the required dry landing distance, or 5458 feet.

The following runway surface condition report (RSC) was passed to the crew via ACARS at 2259: CYFC RSC 15/33 60 PERCENT BARE AND DRY 40 PERCENT ICE PATCHES 9712170254Z; and CYFC JBI 15/33 -8 .48 97120254.

At 2344, while the aircraft was on final approach, the Fredericton FSS specialist advised the crew that the 75-foot centre line was sanded, and that the JBI was 0.40.

After the accident, Bombardier Inc. determined the ground-roll stopping distance that would have been required had the occurrence aircraft touched down at 135 knots. Based on the

no-wind, no-slope, and wet runway conditions, it was calculated that the ground roll required would have been 3059 feet without the use of thrust reversers, and 2640 feet had both thrust reversers been used.

When the go-around was ordered, the aircraft was approximately 1300 feet past the approach end of the runway. At this point the aircraft was 33 feet above the runway, descending at about 500 feet per minute (8.2 ft/sec), and flying at 135 knots (225 ft/sec). If this performance had been maintained to the runway, the aircraft would have touched down in about 4 seconds and

900 feet further along the runway, or approximately 2200 feet past the approach end. Crossing the threshold at about 50 feet on a normal landing, the aircraft should touch down at about

1000 feet past the threshold;[(21)] crossing the threshold at 33 feet would result in a touchdown distance somewhat shorter than 1000 feet, perhaps 600 to 700 feet. Adding 700 to the calculated touchdown distance of 2200 feet, the aircraft would probably touch down within 2900 feet of the threshold. This figure of 2900 plus the ground roll of 3059, as calculated by Bombardier Inc., indicates that it may have been possible for the aircraft to have stopped on the 6000-foot runway.

According to the *AFM*, landing performance is calculated based on the aircraft being over the threshold at a height of 50 feet, in the landing configuration, at the V_{REF} speed, and with the thrust levers retarded to idle. The *AFM* provides the landing field length based on these criteria and the aircraft landing weight.

Based on *AFM* data, crossing the threshold five knots above V_{REF}, rather than at V_{REF}, would result in an increase of approximately 250 feet in the landing field length requirement, which equates to an increase of about 150 feet in actual landing distance.

1.18.2 Approach and Landing Issues

1.18.2.1 Category I and Category II Approaches

Annex 6 to the International Civil Aviation Organization (ICAO) *International Standards and Recommended Practices, Part II, Operation of Aircraft* states that aerodrome operating minima must be established for precision approach and landing operations in terms of visibility and/or runway visual range and decision altitude/height (DA/H) as appropriate to the category of the operation. According to the ICAO *Manual of All-Weather Operations* (Doc 9365-AN/910), a Category I approach is a precision instrument approach and landing with a decision height not lower than 60 m (200 ft) and with either a visibility not less than 800 m (2600 ft) or a runway visual range not less than 550 m (1800 ft). A Category II approach is a precision instrument approach and landing with a decision height lower than 60 m (200 ft) but not lower than 30 m (100 ft), and a runway visual range not less than 350 m (1200 ft). Transport Canada publication TP1490E, *Manual of All Weather Operations (Categories II and III)* contains information similar to the ICAO manual for all aspects of Category II and III precision approaches.

A Category I approach may be flown by a lone pilot with any pilot licence type and an instrument rating, in any aircraft equipped to perform the approach and on which the pilot is rated, to any airport/runway equipped with an operational ILS. There is no requirement that the aircraft be equipped with an autopilot, a radio altimeter, or with duplicate electrical, instrument, or radio systems. The pilot does not require any additional training or experience level to fly the approach.

Because the decision height for Category II approaches is lower than that for Category I approaches, there are special equipment and flight crew requirements relating to Category II approaches, as found in the ICAO and Transport Canada manuals of all-weather operations. For example, the aircraft must have duplicate electrical, instrument, and radio systems, and it must be equipped with an operable autopilot, which must be coupled to the flight director system/ILS down to, at least, the decision height. The airborne and ground-based equipment associated with the ILS systems must meet much more stringent requirements regarding failures, accuracy, and inspections. The airport/runway must be equipped with a backup power system, a sophisticated approach lighting system (see AC in Figure 3), runway centre line and touchdown zone lighting (pictured on the right in Figure 3), and two RVR transmissometers. The airport facilities must be monitored, and someone must be available to advise flight crew of any outages or failures of equipment required for the approach. The aircraft operator must provide detailed procedures in the operations manual. The captain must have at least 300 hours as pilot-in-command and 100 hours line-flying on type, the captain and first officer must have taken and passed an approved program of training, and the flight crew must have proven performance to graduate from Interim

Category II (150-foot decision height) to Category II.

The CL-65 aircraft met all of the requirements for Category II approaches; however, the Fredericton airport facilities and ILS installation were not suitable for Category II approaches. Runway 15 was equipped with AN type approach lighting (see Figure 3), and did not have touchdown zone or runway centre line lighting. The flight crew were qualified to fly to Category II limits, but only if the captain was flying the aircraft with the autopilot coupled.

1.18.2.2 Approach Bans

In Canada, pilots are banned from continuing an approach past the final approach fix to a runway which is equipped with RVR equipment and where the reported RVR is less than

1200 feet. In all other cases, there are no weather-related rules governing when an approach can or cannot be made.

The applicable section of the CARs on approach bans reads as follows:

CAR 602.129 (1) With respect to an aeroplane, for the purposes of subsection (3), the RVR is below the minimum RVR if

(a) where both RVR A' and RVR B' are measured, RVR A' is less than

1200 feet and RVR B' is less than 600 feet;[(22)] or

(b) where only one of RVR A' or RVR B' is measured, the RVR is below

1200 feet.

Reported ground visibility or weather ceilings are not used as the basis for approach bans in Canada. The RVR at Fredericton at the time of the occurrence was reported as 1200 feet and only RVR A' was measured; therefore, there was no restriction to completing the approach.

According to the *FOM*, Chapter 5, Section 5.03.2, if RVR is not reported, then an approach to land may be initiated and continued until reaching the decision height or the visual reference point, as applicable, regardless of the reported ground visibility. This direction is consistent with the provisions in the CARs.

RVR equipment is required only at airports where there are Category II/III landing systems, and RVR equipment has been removed, and more will be removed, from other Canadian airports. With fewer airports having the capability to report RVR, the applicability of the approach ban regulation diminishes and the exposure of operations to poor visibility during landing increases. Transport Canada is currently reviewing this issue in conjunction with the Transport Canada Canadian Aviation Regulation Advisory Council consultations on take-off and approach bans.

1.18.2.3 Approach Criteria

Regulations regarding the conduct of approaches in Canada are found in the CARs. CAR 602.128 states, in part, that for Category I or Category II precision approaches no

pilot-in-command of an IFR aircraft shall continue the final approach descent below the decision height unless the required visual reference necessary to continue the approach to land has been established. The lowest, and normal, decision height in Canada for Category I approaches is 200 feet and for Category II approaches, 100 feet, which is in line with ICAO standards and the standards of other countries.

The following are examples of the approach minima criteria of several countries; the visibility limits, although not described in terms of an approach ban, are effectively approach bans in the Canadian sense:

United States--has the lowest visibility limits for Category I, 1800 feet for airports equipped with centre line lighting. The Federal Aviation Regulations also require that the flight visibility be greater than the visibility prescribed in the standard instrument approach being used.

Australia--the published ILS Category I visibility minima (½ mile) are to be used, unless the high-intensity approach lighting is not available, in which case 1.5 km

($^{9}/_{10}$ mile) visibility is required. If the aircraft is flown not using the autopilot to decision altitude or is flown not using a flight director, then the visibility has to be at least 1.2 km (¾ mile) in order to attempt the approach.

Countries governed by Joint Air Regulations (JARs), which includes many European countries--limits for approaches are dictated by a number of conditions, such as the type of approach and runway lighting, the decision height, and the use of autopilot. For example, for an approach with a decision height of 200 feet, the prescribed visibility limits (RVR) range from 550 m (about 1800 feet or mile) to 1000 m

(3280 feet or about mile).

Canada has filed a difference to Aerodrome Operating Minima in Annex 6, ICAO *International Standards and Recommended Practices, Part II, Operation of Aircraft*, indicating that Canada is not in agreement with some of the ICAO criteria for instrument approaches. In Canada, landings are governed only by the published decision height or MDA, and landing visibilities (other than RVR) are advisory only. No other country has filed an Annex 6 difference for the Aerodrome Operating Minima definition.

The Canadian *Aeronautical Information Publication* (*AIP*), Section RAC 9.20.3, states that the visual references required for the pilot to continue the approach to a safe landing should include at least one of the following references for the intended runway, and should be distinctly visible to, and identifiable by, the pilot:

- -the runway or runway markings,
    - -the runway threshold or threshold markings,

- -the touchdown zone or touchdown zone markings,
- -the approach lights,
- -the approach slope indicator system,
- -the runway identification lights,
- -the threshold and runway end lights,
- -the touchdown zone lights,
- -the parallel runway edge lights, or
- -the runway centre line lights.

The approach and landing minima in the *FOM*, Chapter 5, Section 5.04, contain the applicable excerpts from CARs.

1.18.2.4 Loss of Visual References after Deciding to Land

CARs do not address the situation where visual references deteriorate after having been established. The Air Canada *FOM*, Chapter 4, Section 13.04, does point out the susceptibility to loss of adequate visual references when conducting low-visibility approaches, and directs that a go-around be initiated if adequate visual reference is lost.

The ICAO *Manual of All-Weather Operations* states that training should cover procedures and techniques for reversion to instrument flight and the execution of a balked landing and a subsequent missed approach resulting from a loss of visual references below DA/H or MDA/H.

1.18.2.5 Approach Procedures

Air Canada Approach Procedures

Air Canada, like many other airlines in the world, uses procedures for Category I approaches that require the pilot flying the approach to complete the landing. On final approach, the PNF looks outside the aircraft for the runway environment and, when he or she calls the runway in sight, the PF transitions from instruments to outside references and decides whether to land. After the decision to land is made, the PNF monitors the transition to landing, primarily using outside references with some monitoring of the instruments.

For Category I approaches, crews are given the latitude to decide whether to use the autopilot, and approaches can be flown by either the captain or the first officer. In accordance with existing regulations and training programs, all Air Canada pilots are trained and tested on their abilities to fly Category I approaches to Category I weather limits. There are no minimum experience criteria for flying Category I approaches for either captains or first officers.

For Category II approaches, the captain must fly the approach and landing from the left seat using auto-flight approach couplers. Implied in this statement is that the autopilot must be used to decision height. For aircraft not equipped with autoland, which includes the CL-65, the autopilot must be disengaged prior to 80 feet. In addition, the *FOM* requires the first officer, the PNF, to remain "on instruments" throughout the approach and landing or go-around and to call out deviations and abnormalities indicated on the instruments. In accordance with existing regulations and training programs, all Air Canada pilots are trained and tested on their abilities to conduct Category II approaches, captains performing PF duties and first officers performing PNF duties. The *FOM* also states that captains must have a minimum of 300 hours as

pilot-in-command on turbo-jet aircraft, and that new captains must also have 100 hours on the type of aircraft being flown.

The Air Canada *FOM,* Chapter 4, Section 13.04, specifies additional guidance for conducting low-visibility approaches. It is recommended that the captain fly the approach when the RVR is less than the charted landing visibility, except when the approach is made to a runway with operative high-intensity approach lighting, touchdown zone lighting, and centre line lighting. The use of the autopilot is also recommended when conducting approaches in low-visibility conditions. Air Canada crews are trained to conduct Category II approaches and landings to Category II runways with the RVR at 1200. However, Category I training is not conducted with RVRs less than 2600 to a runway with only Category I lighting.

For Category I approaches, flown to runways without the additional lighting, there are fewer visual cues for touchdown guidance. In addition, the autopilot is not always used for Category I approaches and, if used, is frequently disconnected when the aircraft reaches minima, normally 200 feet agl. Category II lighting is much more effective in that it provides better runway alignment and pitch and roll guidance cues. For Category II approaches, the autopilot is always used to decision height, normally 100 feet, which results in an altitude and distance from the runway threshold from which the visual cues would be better than from the point where Category I decision height is reached: 200 feet above and ½ mile back from the runway threshold.

Alternate Approach Procedures

An alternative to the traditional approach is the pilot monitored approach (PMA), which is intended to enhance the transition to landing during Category I, low-visibility approaches. One pilot flies the approach on instruments, and, nearing the MDA or decision height, the other pilot looks out for visual cues for landing. If the runway environment is seen, the pilot who has been looking out takes control of the aircraft and completes the landing, with the pilot who had been flying monitoring the instruments to touchdown. If the runway environment is not seen, the PF maintains control and performs a missed approach. When weather conditions are at or above approach limits, using PMA techniques provides the landing pilot with more time to assess whether the landing can be made and to better visually determine the position of the aircraft relative to the desired profile.

Several airlines in Canada use PMA procedures when conducting low-visibility approaches; one airline uses such methods when the ceiling is below 400 feet and the visibility is less than one mile. Other airlines use PMA methods to obviate the problem where autopilots cannot be used down to the decision height;[23] PMA methods compensate for the increased pilot workload required because the approach has to be hand-flown to the decision height.

Some pilots who have used both methods have indicated that they prefer the PMA procedure because it eliminates the requirement of having to scan back and forth between the instruments and outside the cockpit as the aircraft approaches decision height. Also, depending on the weather, decision-making time could be available before reaching decision height, i.e., the PNF could be making the landing decision before the PF calls "decision height."

The ICAO *Manual of All-Weather Operations*, in the chapter dealing with Category II approaches, states that pilots must be cautioned against premature disengagement of the autopilot, and that they should continue monitoring flight instrumentation even when adequate visual contact with the runway and its environment can be maintained.

1.18.2.6 Weather-related Occurrences

The TSB reviewed the occurrence rate for visibility-related events, for large aircraft only, in Canada and the USA for the period 1 January 1984 to 30 June 1998. There were 18 landing occurrences in the USA that were directly related to visibility, most of which caused aircraft damage and had the potential of causing injury to those on board. In Canada there were

28 landing occurrences related to visibility, the most serious being this occurrence. Included in the review was research into the amount of time--at 20 selected airports in Canada--when the visibility was less than one-half mile. The accompanying figure represents average values for the period 1983 to 1993.

The greatest number of visibility events occurred at Gander, the airport that has the third greatest amount of time with visibilities less than one-half mile. Two Canadian airlines that use the PMA techniques did not have any reported visibility-related landing occurrences even though one of the airlines has high rates of exposure to low-weather approaches. There was one visibility-related occurrence for a Category II approach in Canada.

A review of the occurrences in Canada showed that the main reason for many of them was the lack of adequate visual references, firstly, to give pilots a clear understanding of where the aircraft was relative to the desired profile and, secondly, to allow pilots to maintain or correct to that profile.

1.18.3 Aircraft Performance

1.18.3.1 General

It was established early in the investigation--through FDR information and crew interviews--that the aircraft did not perform as expected during the attempted

go-around. There were two areas where the performance was not as expected: first, the SPS pusher did not activate to prevent the aircraft from stalling and, second, the aircraft stalled at an AOA and coefficient of lift (C_L) lower than expected. A concerted effort was undertaken to examine the functioning of the SPS and the aircraft aerodynamics to explain these discrepancies.

1.18.3.2 Stall Protection System Activation

As stated, the recorders indicated that during the accident sequence the shaker and the warbler activated, but the pusher did not. The behaviour of the SPS during the last eight seconds of the flight was analysed. The left-hand and right-hand AOA vane angles as recorded on the FDR were compared with the shaker and pusher boundaries adjusted for the phase advance resulting from the rate of increase of aircraft AOA. This comparison revealed that both AOA vanes reached the shaker trip point, but only the right-hand vane reached the pusher trip point and, as a result, the warbler activated but the pusher did not. Both vanes have to reach the pusher trip point before the pusher will activate; the aircraft stalled aerodynamically just before this was about to happen. Analysis of the performance of the SPS indicates that the system operated as designed: that it did not prevent the stall is related to issues discussed later in this report.

1.18.3.3 Coefficient of Lift Curve

Appendix C is a plot of three curves (coefficient of lift versus AOA) for the last eight seconds of the flight. The solid line represents the expected C_L-alpha curve based on certification flight test data in free air and at an entry rate of less than one knot/sec. The dotted line depicts the C_L-alpha curve computed by Bombardier for the accident flight, and the line with the triangular points is the curve computed by the Institute of Aviation Research (IAR), a division of the National Research Council (NRC) of Canada. Also shown on the graph is the position of the natural aerodynamic stall for a clean (uncontaminated) wing.

Bombardier and IAR, each using a different technique, independently computed the lift coefficient for the accident flight using FDR data. The results each obtained correlated reasonably well considering the dynamics of the aircraft just prior to roll-off (during the last eight seconds the aircraft was pitching up and decelerating while coming under the influence of ground effect) and the low sampling-rate of the FDR.

There are significant differences between the expected and computed curves as follows:

- -The computed curves are displaced below the expected curve such that for a given AOA the coefficient of lift is reduced except in the area approaching the stall where the computed curve approximates or is slightly higher than the expected curve.

- -The accident aircraft stalled at an AOA that was approximately 4.5 degrees lower than expected for the natural stall.

- -The maximum lift coefficient (C_{Lmax}) achieved was approximately 0.26 lower than expected for the natural stall.

1.18.3.4 Flight Data Recorder Data from Previous Flight

The C_L-alpha curve for the approach phase of the previous flight starting at 1000 feet agl was computed and compared with the curve generated for the accident flight for the same phase of flight. On the previous flight, the aircraft was operated within a narrow range of AOA and, therefore, the data available for calculating the C_L-alpha curve were similarly limited. Extrapolation of this curve to higher AOAs was not considered to be valid. As a result, no meaningful comparison of lift curve slope and, therefore, of aircraft performance could be made. These curves did not allow a comparison of C_{Lmax} or the stall AOA, as the previous flight was not operated in or near this flight regime, that is, at high AOAs.

Drag coefficients, a graph of C_D versus C_L^2, were plotted for the accident and previous flight; the data used for each flight were from the approach phase of flight, below 1000 feet agl. NRC interpretation of the data indicated that the C_D of the accident flight was 0.014 higher than that of the previous flight. Bombardier interpretation of the data indicated that the drag levels were very similar in each of the two flights. To date there has been no resolution of the different results.

1.18.3.5 Flight Data Recorder Data from Aircraft 104

For the purposes of comparison, performance analysis was conducted on another CL-65 aircraft in the Air Canada fleet. Aircraft 104 was chosen because its performance closely resembled the performance of aircraft 109, the accident aircraft. These performance assessments were based solely on a fleet comparison of fuel consumption figures. FDR data from aircraft 104 were analysed with data taken from three flights that occurred before (flight 1), during (flight 2), and after (flight 3) the Air Canada wing improvement program (see Section 4.1.5). The leading edge of the wing was polished prior to flight 2 and the remaining maintenance actions were done after flight 2 but prior to flight 3. C_L-alpha curves were computed from data taken from all three flights. Again, because of the limited alpha range, no firm conclusions could be drawn from a comparison of these curves.

Drag coefficients were calculated and plotted using data from the three flights. The drag coefficient from flight 1 was very similar to the drag coefficient for the accident aircraft for the flight previous to the accident flight. The drag coefficients for flights 2 and 3 showed improvements over flight 1 of C_D=0.0043 and C_D=0.0044, respectively, as the wing leading edges were first polished, and then the wings were repainted and leading edge sealant was replaced.

1.18.3.6 Simulator Comparison

The aerodynamic simulation model used in the CL-65 engineering flight simulator was used to re-create the final stages of the accident flight. The simulation model's output was directly compared to the FDR data. The simulation was initialized on final approach at a pressure altitude of 1265 feet (a radar altitude of 1020 feet) with the same flight parameters and aircraft configuration as determined from the FDR.

The simulation was set up to run from the initial conditions to the point where the aircraft stalled. The first run indicated differences between the FDR flight profile and the simulator flight profile with an abrupt change in the FDR aileron deflection as the aircraft descended through 620 feet pressure altitude (400 feet agl). Subsequent runs were conducted with lift, pitching moment, yawing moment, and rolling moment coefficient increments added until a reasonable correlation was achieved between the FDR profile and the simulation profile. All four increments required to achieve correlation show two significant step changes with the first at 400 feet agl and the second, 23 seconds later, at 150 feet agl. In the case of the longitudinal coefficients (lift and pitching moments), the change is amplified on the second step. For the lateral and directional coefficients (rolling and yawing moments), the second step change is in the opposite direction and of similar magnitude, effectively "cancelling" the initial change. It was concluded that the lift losses were a result of local flow separation in the area of the leading edge cap, located between WS 247 and WS 253.

1.18.3.7 Wing Condition

Wing Paint

The leading edge of the CL-65 wing consists of a number of flush-rivetted panels, removable panels, and removable fillets. These panels and fillets are unpainted. The wing aft of the leading edge panels is painted white. The paint immediately aft of the leading edge (approximately 8% chord) on both the upper and lower surfaces of both wings was not adhering in some areas.

The paint in this area was cracked and, in certain places, was peeling or flaking. Touch-up paint had been applied; the right wing showed more paint loss than did the left.

Surface Pitting

Both wings of the accident aircraft had numerous small indentations in the vicinity of the leading edges. The indentations were more numerous and larger in the wing root area with the number and size diminishing progressively further outboard on the wing. This damage was considered to be typical of erosion caused by sand and other matter thrown up by the nose wheel as a result of normal in-service use. This leading edge pitting was fairly typical of other aircraft in the Air Canada CL-65 fleet, and was within the limits specified in the CL-65 Structural Repair Manual. The amount of pitting is considered to be a normal, in-service condition.

Leading-Edge Sealant

Chordwise between all the panels and fillets that make up the leading edge and spanwise between the leading edges and wing planks, there are small gaps approximately 0.1 inch wide. Sealant fills these gaps to ensure that the wing has good aerodynamic properties. The sealant on neither wing was in an "as-delivered" condition. The sealant was missing in some places and in other places protruding 2 to 3 mm from the surface of the panel or fillet. The overall condition of the sealant on the right wing was slightly more degraded than that on the left wing. The chordwise sealant covers a small part of one percent of the leading edge area. The protruding sealant can produce a significant detrimental effect on the airflow over the wings at high angles of attack. The sensitivity of the CL-65 wing to its surface condition was not made apparent in either the approved maintenance program, the maintenance manual, or the aircraft operating manual.

Flight tests were conducted to determine the aerodynamic effect of the extruded sealant. The test program comprised two flights, the first with the wings in a clean condition, as per the current CL-65 production standard, and the second with the chordwise sealant (simulated) protruding or missing as on the wings on the accident aircraft. The flights were conducted with the flaps set at 45 and the landing gear down, at approximately the same weight/delta (weight divided by the pressure ratio) and centre of gravity as the accident aircraft. Each flight consisted of natural (aerodynamic) stall tests to define the stall point, and slowdown manoeuvres to define the aircraft lift-curve slope. The test results showed a reduction in maximum fuselage AOA of 1.7 to 2.0 degrees, and a reduction in C_{Lmax} in the order of 0.03 to 0.05. The reproduction on a test aircraft of shapes to imitate the extrusions produced results that are only representative of the degradation in performance caused by the extruded sealant.

1.18.3.8 Ground Effect

When an aircraft in flight nears the ground, a change occurs in the three-dimensional flow pattern around the aircraft. While the aerodynamic characteristics of the tail and fuselage are altered by ground effect, the principal effect due to the proximity of the ground plane is the change in the aerodynamic characteristics of the wing. For ground effect to be significant, the wing must be quite close to the ground plane, typically half the wingspan or lower in height. In ground effect, a lower AOA is required to produce the same lift coefficient or, if a constant AOA is maintained, the lift coefficient will increase.

A review of literature regarding how ground effect alters aircraft stall characteristics was carried out. Although it is known that there is a definite reduction in stall AOA and C_{Lmax} due to ground effect, the review revealed that the available flight data were very limited and analysis techniques were not reliable. Notwithstanding these limitations, an attempt was made to quantify the impact of ground effect on the aircraft coefficient of lift and AOA for the accident flight, which indicated that the ground effect at the point of wing roll-off was likely to have caused a small lift increase (in the order of 2%) and a reduction in AOA of less than 0.3 degree for the same lift.

1.18.3.9 Ice Accretion

Accretion Studies

Two separate studies were conducted, one by IAR and one by Bombardier, on possible ice accretion on the aircraft during the period it was on the approach. Although the results of the two studies differ somewhat, the nature of studies of this type is that there is limited accurate information available to begin with and the analytical process is in part subjective, requiring opinion and interpolation based on experience with similar meteorological conditions. Many of the results have fairly wide tolerances and, therefore, can be considered to indicate the "order of magnitude" expected. Given these circumstances, the results of the two studies are considered to be similar and the following conclusions can be drawn:

- -The aircraft was in an icing environment for at least 60 seconds prior to the stall, and during this period a thin layer of mixed ice with some degree of roughness likely accumulated on the leading edges of the wings.

- -Leading edge roughness from contamination similar to that predicted by the studies could result in a decrease in AOA of 5±1.25 degrees at maximum lift and a corresponding reduction in C_{Lmax} of as much as 0.43±0.04.

- -The rate of ice accretion predicted would not have been sufficient to trip the ice detector before the aircraft reached 400 feet agl (see last paragraph of

Section 1.18.3.10).

Observed Conditions

Examination of the aircraft wings and other surfaces at the accident site did not reveal any sign of ice accretion on the aircraft. In addition, the crew did not observe any indications of airframe or windshield icing. Because the ice accretion studies indicated that the aircraft was in icing conditions for at least 60 seconds prior to the accident, the possibility was examined that any accreted ice was lost during the accident sequence or sometime thereafter.

The aircraft struck the runway (twice) and the drainage ditch (once) with considerable force. This could have jarred or knocked ice off the aircraft structure. After striking the ditch, the aircraft travelled approximately 1000 feet over or through a snow-covered surface. The resulting abrasion from the snow on the wing surfaces could have removed adhering ice. The aircraft struck the small hill and trees just prior to coming to a stop; these impacts could also have dislodged ice from aircraft surfaces.

Most of the aircraft passengers exited from the aircraft through the emergency exits onto the wing surfaces and then down to the ground. This evacuation activity on the wing surfaces combined with the subsequent rescue activities in the same area could have further disturbed or dislodged ice.

On the day following the accident, the visibility gradually improved through the morning. Photographs taken of the wreckage that morning show patches of clear sky, and direct sunshine falling on parts of the aircraft, although the temperature was below zero all day. This solar radiation could have sufficiently warmed the aircraft surfaces to cause sublimation of the very thin layer of ice that was postulated by the accretion studies to have formed.

1.18.3.10 Ice Detection and Protection

CL-65 aircraft ice and rain protection consists of wing, cowl, and windshield anti-icing systems. This discussion will be limited to a discussion of the ice detection system and the ice protection system.

The ice detection system consists of two probes, mounted on opposite sides of the forward, lower area of the fuselage. Under the influence of a modulated magnetic field, the probes oscillate along their axes at 40 kHz. When the aircraft enters an icing environment, ice collects on the probes, and the added mass of ice causes the oscillating frequency of the probes to decrease. A nominal mass of 80 mg (±25%) on the probes causes the operating frequency to decrease by approximately 130 Hz. The probe manufacturer stated, based on years of experience, that this mass corresponds to an ice thickness of about 0.020 inch. Ice detector software monitors the probe frequency; at approximately 130 Hz with the wing/cowl anti-ice switches selected OFF, the amber ICE light on the ANTI-ICE panel illuminates to indicate icing on either probe. At the same time the Engine Indicating and Crew Alerting System (EICAS) ANTI-ICE page annunciates an amber "ICE 1" or "ICE 2" (depending on which probe has detected ice). Selection of the wing/cowl anti-ice switches to ON causes the amber ICE light to extinguish and the ICE 1/ICE 2 annunciation to change to white. At this point the probe heaters are automatically activated and the probe frequency rises as the probe is de-iced. At a predetermined frequency, the heaters are deactivated and the probes quickly cool, ready to sense ice formation again. The ice annunciation stays on for a nominal 60 seconds. This 60-second timer is reset each time sufficient ice forms on the probes to decrease the frequency by 130 Hz, thus providing a continuous ice annunciation until the aircraft is out of the icing conditions.

When switched on by the crew (with or without illumination of the amber ICE light or EICAS message), the wing anti-ice system routes bleed air to a chamber behind the leading edge of the wing to de-ice the leading edge area and prevent further ice accumulation. After both the wing and cowl anti-ice systems are switched on, the amber ICE light will extinguish, and a white ICE status message will post on the EICAS ANTI-ICE page. The crew will leave the wing and cowl anti-ice on as long as the white ICE status message is being annunciated. The amber ICE light is inhibited below a radio altitude of 400 feet with the landing gear extended.

2.0 Analysis

2.1 Introduction

The flight was unremarkable up to the arrival at decision height on final approach to Fredericton. Examination of the wreckage, individual components and maintenance records, and interviews with the air crew and passengers yielded no indication that the aircraft malfunctioned or suffered a failure during the flight. All ground navigation and landing aids on or near the Fredericton Airport were serviceable and operating normally. The aircraft was on an authorized flight and was being flown in accordance with applicable regulations and procedures by a qualified crew.

Many factors were involved in this accident: the weather, darkness, flight crew training and aircraft knowledge, aircraft handling, aircraft operating procedures, aircraft performance and limitations, Canadian Aviation Regulations, runway lighting, dissemination of information, aircraft design and certification, and overview of operations. The weather, with a low ceiling and low visibility in fog, was the one factor that led to the interaction of all the other factors and, finally, to the accident.

The number of issues which, combined, created a window of opportunity for this accident, suggests that there was inadequate safety management oversight for the CL-65 program. Neither Bombardier Inc., nor Transport Canada, nor Air Canada ensured that the regulations, manuals, and training programs prepared flight crews to successfully and consistently transition to visual flight for a landing or to go-around in the conditions that existed during this flight, especially considering the energy state of the aircraft when the go-around was commenced. While these issues have been analysed, the relationship of some issues to a particular organization have not been drawn.

The analysis is structured into three main parts--Survival Aspects, Operational Issues, and Performance Issues. As there were no pre-accident unserviceabilities or failures found relating to the aircraft or ground equipment, there is no analytical discussion in these areas.

2.2 Survival Aspects

2.2.1 Training on Evacuation and Emergency Equipment

In the aftermath of an aircraft accident, especially where there is only one flight attendant, flight crew may be the only crew members available to conduct an evacuation and direct passengers after the evacuation; therefore, it is imperative that they have the knowledge and skills to conduct the evacuation. Although CARs state that, during training, practical training must be completed on emergency exits, Air Canada provides practical training on doors only, and the occurrence pilots did not receive practical training on doors or any other exits. Practical training on the operation of the aircraft doors may have been omitted during the flight crew-members' initial training because (a) it was not stated as a training objective in Air Canada's *Flight Crew Training Manual*--Line Indoctrination and (b) "operation of emergency exits" was not included as an action item on the *Pilot Line Indoctrination Checklist* used by the flight instructors or the line indoctrination training captain. When an action item is not included in the related checklist, there is a risk that the item will be omitted, as evidenced by this occurrence. Although operation of emergency exits by flight crew was not an issue in this occurrence, there is a risk that in other circumstances this lack of practical training could present a problem.

The flight crew were unaware that there was a pry bar on the aircraft, and that it was standard emergency equipment. Although "location and use of emergency equipment" is a line indoctrination training objective, it is not included as a check item on the *Pilot Line Indoctrination Checklist.* Given that the pry bar was stronger than the crash axe, the pry bar may have been a more effective tool to use when, for example, the flight crew attempted to free the trapped hand of one of the passengers.

Flight attendants do not receive practical training on the operation of the flight-deck escape hatch. It is recognized that the primary purpose of the escape hatch is to evacuate flight crew, not passengers, and that it is to be used by flight attendants only as a last resort. Nevertheless, there is a possibility that a flight attendant would be required to open the escape hatch following an aircraft accident.

2.2.2 Survival Equipment--Signalling Tools

There was no requirement for the carriage of survival equipment that would provide the means for "visually signalling distress." The only equipment available to signal were the emergency flashlights. Although the flight attendant and subsequently a passenger repeatedly signalled using a flashlight, given the reduced visibility in dense fog it was not an effective signalling tool, and they were unsuccessful in attracting attention. As a result, emergency response services (ERS) personnel did not know the location of the aircraft until a passenger reached the runway and gave them directions, approximately 15 minutes after the accident.

This occurrence has shown that effective signalling equipment is required, even when an accident occurs at an airport. Any circumstance that impedes, or does not facilitate, a timely response by emergency personnel can be hazardous to the survival of passengers and crew.

2.2.3 Emergency Equipment--Location of Flashlights

Although emergency flashlights were not effective in signalling the rescuers, they were useful in other ways during the evacuation. It was noted that the emergency flashlights are all stored in the same general area, three in the flight deck and one just outside the flight deck, in the storage area under the flight attendant's seat. Placement of the flashlights in this manner facilitates ready access by the crew, which is essential in an emergency. However, locating all units of one type of emergency equipment in the same area may be inappropriate; during an accident, damage to that one area of the aircraft could render all units inaccessible or unserviceable.

2.2.4 Passenger Preparedness for Post-Evacuation Survival

The passengers responded quickly and appropriately to the flight attendants' commands during the evacuation. Many of the passengers were not appropriately clothed for the cold weather; they escaped severe discomfort, and perhaps injury, only because of the location of the crash site and the relatively short time they were exposed to the cold and snow.

2.2.5 Emergency Response

Emergency response personnel, impeded by darkness, dense fog, and deep snow off the runway surface, took about 15 minutes to locate the crash site. Snow removal equipment was subsequently dispatched and used to clear a roadway through the snow to the site, with the road being useable 50 minutes after the crash. The local emergency response plans were activated about 10 minutes after the crash, and key personnel and units, e.g., community firefighters and the hospital, responded quickly. Although it took 50 minutes to find the aircraft and clear a route to it, it is concluded that the response of the emergency response services was as effective as the conditions and equipment would permit. Although the rescue did take a relatively long time, this was largely because of the difficult circumstances faced by the persons involved with the rescue of the trapped passengers.

2.3 Operational Issues

2.3.1 Approach and Transition to Land

2.3.1.1 Approach Ban Weather Limits

Research into occurrences in low visibility has indicated that there are many more occurrences during Category I approaches than during Category II. The exposure rate for Category I approaches is higher because of the few times that weather is at a Category II limit and because there are only a few airports in Canada equipped for Category II approaches. However, in many of the landing occurrences in Canada, the Category I approaches that have resulted in runway excursions, hard landings or wing scrapes have had a common element: an unsuccessful transition to a visual landing due to an absence of some or all of the aids and defences used in Category II operations. These aids and defences are detailed in section 1.18.2.1. Many of the occurrences stem from the premature disconnection of the autopilot or from not using available auto-flight equipment. Other occurrences involved a loss of some visual cues after the decision height, when the landing pilots attempted to orient themselves for landing on runways with inadequate cues.

In this occurrence the approach was conducted in accordance with the regulations of Canada. These regulations are more liberal than those of most countries and are not consistent with the ICAO *International Standards and Recommended Practices* (Annex 14), which defines visibility limits; in Canada the visibility values are advisory only.

The lower the approach ban visibility, the more likely it is that a pilot will encounter situations where a landing is being conducted in conditions where the view of the landing environment is not clear; the less clear the view, the more difficult the transition from approach to landing. As the incidence of visibilities below one half mile is low for most Canadian airports, it may be that raising the approach ban minimum RVR would have only a slight effect on flight operations.

2.3.1.2 Weather Conditions and Effects on this Flight

Although the 100-foot ceiling and -mile visibility reported for Fredericton was below the charted ½ -mile (RVR 2600) visibility and 200-foot decision height for the approach, the approach was permitted because the reported RVR of 1200 feet was at the minimum RVR to conduct an approach, as specified in CAR 602.129. In addition, based on the crew having the runway approach and threshold lights in sight at decision height, the decision to land was in accordance with operating procedures. Under the regulations of the majority of other nations, this approach in the same weather conditions would not have been permitted because of the low RVR.

The ILS approach to runway 15 at Fredericton was a Category I approach; however, the weather conditions were those normally associated with Category II approaches, and some aids and defences identified as needed for Category II approaches were not available or not used. There was no centre line runway lighting, no touchdown-zone lighting, the captain was not required to fly the aircraft, and the autopilot was disengaged at a height above where it would be disengaged on a Category II approach. Further, the first officer had no training or experience on the CL-65 as the pilot-flying, to a landing, in weather conditions normally associated with Category II approaches, and neither crew member had specific training in flying Category I approaches to a landing in the same weather conditions. Flying without some of these important aids and defences, to the same weather limits, increases the probability that the approach will not lead to a successful landing. There is a comprehensive list of equipment, training, and operational requirements for Category II approaches in section 1.18.2.1; the preceding are those aids and defences that were directly related to this occurrence.

In the occurrence environmental conditions, the lack of runway centre line and touchdown-zone lighting probably contributed to the first officer not being able to see the runway environment clearly enough to enable him to maintain the aircraft on the visual glide path and runway centre line. Also, disengagement of the autopilot at decision height rather than at the 80-foot minimum autopilot altitude resulted in an increased workload for the PF and allowed deviations from the glide path for a longer period (during hand-flying). As well, an autopilot will normally place an aircraft accurately on the glide path, which results in the runway environment, when close to touchdown, being directly ahead of the aircraft, giving the pilots better visual cues for landing and reducing the corrections required for line-up with the runway once the autopilot is disconnected.

The deviations from the glide path and centre line were probably precipitated by the limited experience of the first officer on the CL-65 and his limited experience on the CL-65 in low-visibility conditions. The tendency of the aircraft to pitch up when thrust is reduced, and the illusion of the nose being too low and the descent rate too high, resulted in glide-path deviations that were not overcome, even with prompts by the captain. As well, limited visual cues probably contributed to the first officer's not maintaining the aircraft near the centre line of the runway. At 200 feet, the aircraft was slightly right of the localizer and was heading a few degrees right to compensate for the right crosswind--the wind decreased from 10 knots at

200 feet to calm at the surface. When the first officer applied left rudder and aileron to align the aircraft with the runway, he did not perceive the resulting left bank. Although right rudder was applied as the aircraft crossed the centre line of the runway, the rudder application did not counter the aerodynamic effect of the left bank, and the aircraft continued to move to the left side of the runway.

2.3.1.3 Low-Weather Procedures

The procedures used by Air Canada create a higher workload for the pilot landing the aircraft than is the case for pilots of airlines that use PMA methods. Also, while there may be other factors at play, the TSB review of the landing occurrences shows that airlines using PMA techniques have few landing occurrences related to low visibility. The difficulty stems from the requirement (when using the traditional non-PMA techniques) for the landing pilot to scan in and out of the cockpit as the aircraft nears decision height. In this occurrence, the decision to land was made approximately three seconds after the runway-in-sight call. The verbalized decision to continue for the landing was made when the aircraft was about 165 feet agl, not at 200 feet. This situation is almost inevitable when the weather is at limits and the landing pilot must fly with reference to the instruments until reaching decision height.

Some airlines use a technical defence--a head-up display--to enhance safety during the approach and landing. The head-up display permits the landing pilot to observe the aircraft performance while looking through the windscreen for visual cues for the landing.

2.3.2 Assigning First Officer Pilot-Flying Duties

Air Canada procedures recommend that the captain fly the approach when the RVR is below the charted visibility; however, there was nothing in applicable manuals prohibiting the first officer from flying the approach. The captain's decision to let the first officer fly the approach was based on the following: before leaving Toronto, the captain had assigned the first officer as the PF on the Toronto to Fredericton leg of the flight; the first officer had demonstrated competent flying skills during the three legs flown together; the first officer stated that he had experience in low-weather approaches; and flying this approach would increase the first officer's flying experience. Other factors that supported the captain's decision were that he himself had successfully flown the CL-65 in low weather before and was comfortable with landings in 1200-RVR conditions, as long as the required outside references were visible at or above minima. In addition, there was always the option of discontinuing the approach and doing a go-around if weather conditions precluded a landing. In conclusion, the captain saw no compelling reason to change from his original assignment of flying responsibilities. However, based on the weather and visibility, runway length, approach and runway lighting, runway condition, and the first officer's flying experience, allowing the first officer to fly the approach is questionable.

The first officer allowed the aircraft to deviate from the flight path to the extent that a go-around was required, which is an indication of his ability to transition to landing in the existing environmental conditions. The first officer's inexperience and lack of training in flying the CL-65 in low-visibility conditions contributed to his difficulty in completing the transition to land.

2.3.3 Captain Duties on Approach

During the approach, the captain was responsible for the duties of both the captain and the PNF and, as such, was monitoring the first officer's performance and the flight of the aircraft by referring to outside references and the aircraft instruments. Neither the captain nor the first officer remembers hearing the RADALT calls ("50," "30," and "10") during the initiation of the go-around. These calls indicate the aircraft's height above ground during the landing. Once a go-around is initiated, however, their relevance as crucial information to the task is diminished. In carrying out a critical and demanding task, such as a go-around, people are inclined to attend to and process that information they need to perform the task and discard or not attend to that information which is extraneous to the task. When the 50-foot call sounded the captain was in the process of initiating a go-around and most likely did not attend to and process the altitude information because of the change in plans and the 50-foot call's relevance to the go-around. As the go-around had already been initiated when the 30- and 10-foot calls sounded, they were no longer relevant to the go-around, and it is probable that they were not attended to for that reason. Also, he was not aware that the engines had spooled down to idle. A captain, when not the PF, would rarely call for a go-around; in this case, the captain omitted to call "flaps" at the time of calling for a go-around. As well, the first officer, when acknowledging the go-around, did not mention flaps. (The stick shaker activated about one second after the first officer started his acknowledgement.) The uncertainty over the advancement of the power levers for the go-around, and the fact that neither pilot called for flaps at the time of the go-around call or acknowledgement, may have been the result of the unanticipated and rare situation and of the interruption caused by the stick shaker. The allocation of responsibilities between the PF and PNF during a go-around is generally unambiguous; however, the situation of a captain being the PNF when ordering a go-around is not covered in any operations manuals applicable to the CL-65 aircraft.

Although it was about a second and a half between the time that the go-around was acknowledged and the time that the speed of the engines started to increase, the conclusions of the technical analysis of the engine accelerations indicate that this time period and the engine acceleration rates were consistent with what would have been expected had the thrust levers been slammed to the go-around thrust setting. The three seconds between the go-around acknowledgement and the flaps call would account for about nine degrees of flap retraction; however, the resulting higher drag had only a minimal effect on aircraft performance during the go-around attempt.

During the initial transition from decision height to the attempted landing, the captain assessed that the pitch deviations were minor and assumed that a prompt from him would elicit the effective corrective actions by the first officer. The captain's assumption was validated when the first officer reacted to the first prompt. When the second prompt did not result in a continued, satisfactory descent and the aircraft moved too far left of the centre line, the captain ordered the go-around. The captain was not aware of the low-energy state of the aircraft, primarily because he had not noted that the throttles had been reduced to idle and, because he was focussing his attention on the landing environment and not the instruments, he had no indication that a safe go-around might not be possible. Consequently, the captain saw no reason for him to change from the plan for the first officer to conduct the go-around.

2.3.4 Go-around Issues

2.3.4.1 Low-Energy Rejected Landing Considerations

According to Transport Canada, when the go-around was initiated, the aircraft was outside of the flight envelope demonstrated during the certification process. Specifically, the retarding of the thrust levers to idle, and leaving them there until the aircraft was lower than 50 feet, was tantamount to a commitment for landing, and placed the aircraft into the low-energy regime from which a go-around could not be completed without contacting the ground. The reduction of thrust to idle was made in response to the captain's coaching and because the aircraft was on-speed and above the desired glide path. The significant difference between the occurrence go-around and go-arounds practised in training was the low-energy state of the aircraft, the most significant being the low engine thrust. Even though the thrust levers were advanced when the go-around was acknowledged by the first officer, it took the engines five seconds to reach the approach thrust level that would normally be the starting thrust level for the go-around. During these five seconds, the aircraft was not in a condition either to accelerate in level flight or to climb without losing airspeed.

The certification process assessed aircraft performance during go-around; however, as the conditions under which the go-arounds were performed did not form part of the go-around documentation, these conditions were not taken into account when the go-around procedures were written into aircraft and training manuals, and when training was provided to flight crews. The go-around conditions for certification are not mentioned in the *AFM*, the *FCOM*, the *AOM*, or training manuals; the only published restriction in the *AFM* regarding go-around procedures states that a go-around manoeuvre should not be attempted after the thrust reversers have been deployed. Nowhere in the applicable manuals is it reflected that a safe

go-around, without ground contact, will probably not be possible once power is reduced to idle for landing: this assumes that the reduction to idle power is made at a normal height and position relative to the runway.

It is recognized that issues discussed in this section are not unique to the CL-65 aircraft and its certification. Because of the complexity and the interaction of the variables involved, it may not be practicable or possible to provide data indicating when a safe go-around could not be expected. However, operators and pilots could be provided with the go-around conditions related to certification so an interpretation of what may not be possible could be made.

2.3.4.2 Flight Director Guidance

The aircraft operating philosophy stressing that the flight director commands must be followed for proper flight control is valid for most anticipated flight conditions. Notwithstanding, not all commanded pitch attitudes are achievable or safe. In particular, following the command bars in go-around mode does not ensure that a safe flying speed will be maintained because, unlike in the windshear guidance mode, the positioning of the command bars does not take into consideration the airspeed, flap configuration, and the rate of change of the AOA--all factors to consider in achieving an adequate stall margin.

The high level of concentration required during a go-around and the limited time available may limit a pilot's ability to recognize and react to indications from other instruments. In this case, rotating the aircraft toward the command bars was a priority task for the first officer, and the level of concentration required to get the aircraft pitch to match the command bars probably affected his ability to adequately monitor the airspeed. The command bars, by directing the pilot to pitch the aircraft to 10 degrees nose-up without taking into account stall margin factors, probably contributed to the onset of the stall.

2.3.4.3 Go-around Procedure and Training

The direction in the go-around procedure (as presented in the *AFM, AOM,* and training manuals) to rotate the pitch *toward* rather than *to* the flight director command bars was intended to emphasize that the flight director guidance was an initial reference and to promote airspeed awareness during the go-around. However, the go-around procedure, in directing the pitch adjustment prior to noting the climb speed requirement of V_2 + 10 knots, places some precedence and importance on achieving the pitch change. In addition, the sequential nature of steps within the procedure, and the high level of concentration required when initiating the go-around, can result in the passage of a critical amount of time before the airspeed is considered by the pilots. These factors would be more pronounced for pilots who have low flight-time on the aircraft and low experience with the procedure.

Various conditions and configurations for go-around are demonstrated during training; however, practice go-arounds are normally initiated from a stabilized approach. When

go-around thrust is selected, aircraft speed increases almost immediately, and rotating the aircraft nose-up, toward the command bars, does not result in airspeed loss. In this case, immediate and frequent monitoring of the aircraft's speed is not required. When practising

go-arounds from single-engine approaches, or in response to wind shear, pilots must closely monitor the airspeed. Based on their training, the occurrence pilots' interpretation of the procedure was that the aircraft was to be rotated to the command bars as the first step of the

go-around procedure.

There are at least four instances in various CL-65 manuals in use by Air Canada where the

go-around or rejected-landing procedure is described, and all are slightly different. The

Air Canada *Flight Crew Training Manual, Student Study Guide* (Publication 595) provides a description of the Go-around Technique, which is a good description of the actions that pilots should take in completing a go-around. The procedures to be followed are as outlined in the *AOM*; however, the narrative in the study guide describes the procedure in detail and tells the pilots how to fly the go-around, with appropriate tips and cautions.

2.3.5 Flight Monitoring

During the approach to the 50-foot RADALT call, the airspeed would have been within the magenta airspeed bug. Consequently, the information provided by the bug airspeed reading would not have provided compelling cues that adjustments to the airspeed were required. At

50 feet, the airspeed trend vector would have shown a predicted decrease in airspeed of about 10 to 15 knots, which would be expected during this phase of an approach.

When the go-around was initiated, the airspeed indications would have provided substantial cues that something was amiss: the magenta airspeed bug would have been 12 knots above the airspeed pointer; the low-speed, red/black checkerboard band would have been about 5 knots below the pointer; and the magenta airspeed trend vector would have been predicting a decreasing airspeed trend of approximately 25 knots, which would have extended well into the low-speed band. The first officer's ability to recognize these airspeed cues and react to them before the stick shaker activated would have been adversely affected by the following: during his go-around training, airspeed always increased immediately when thrust was applied; he initially was occupied with rotating the aircraft up toward the command bars; and there was only two seconds between initiating the go-around and the activation of the stick shaker. The time required to recognize the problem and determine a course of action in response to the stick shaker would have reduced the time available for the first officer to take action to increase the airspeed before the aircraft stalled.

Because of his involvement in setting the go-around thrust, the captain's monitoring of the flight during the go-around was limited. The setting of go-around thrust spanned the entire

go-around event (less than three seconds), up to and including the point of the warbler tone activation, when the engine N_1 readings, then at the 35% range, were still significantly below the go-around setting. A closer monitoring by the captain of the transition to land and the

go-around attempt may have induced him to take some type of corrective action prior to the aircraft's stalling.

2.3.6 Stall Recovery Procedures

When the first officer initiated the go-around, he pulled the control column back rapidly, which changed the elevator position from the minus 4-degree range during the landing attempt to minus 12-degree range when the stick shaker activated. Although he may have stopped pulling back and eased forward slightly on the control wheel, the elevator position was such that the pitch attitude of the aircraft continued to increase from plus 4.0 degrees to plus 9.5 degrees by the time of stall onset and right roll. In effect, the reduction in nose-up elevator position from the minus 12-degree range to the minus 8-degree range one second following the stick shaker activation was insufficient to meet the stall recovery objective of maintaining the aircraft attitude. The subsequent reduction of nose-up elevator to minus 3 degrees could have been associated either with an attempt to stop the nose from rising above the command bars or with an attempt to recover from the stall warning.

The maximum engine N_1 speeds achieved following the stall were in excess of the go-around thrust setting. This higher thrust setting could have been the result of one or more of the following factors: the captain's positioning of the thrust levers for the go-around; the captain's reaction to the stall symptoms; or the forces experienced by the aircraft during the accident sequence.

The circumstances at the time of the stick shaker activation were somewhat different from those experienced during stall recovery training. During practice landing-configuration stalls, smooth, continually increasing back pressure is applied to the point of the stall, and only a slight decrease in back pressure and almost no control column movement are required to maintain the pitch attitude. For the occurrence flight, a significant change in control column position would have been required to move the elevator position from the minus 12-degree range to the position needed to stop the nose from rising. The training scenarios and profiles did not emulate the circumstances and control-input requirements for the occurrence stall. The first officer's reaction to the stick shaker was in keeping with the type of response practised during stall training.

When the stick shaker activated, the aircraft was at 14 feet agl, descending at about 350 feet per minute at 129 knots and pitched up at 4.0 degrees. Holding the pitch attitude at 4 degrees would have resulted in a continued descent, and the aircraft would have touched down in about two seconds. Based on the FDR-derived rate of airspeed loss of 2.7 knots per second at the time the shaker activated, the airspeed would have decayed to about 124 knots in the two seconds.

When the warbler sounded, the aircraft pitch was 9.7 degrees above the horizon. Transport Canada certification testing data indicate that, had the pusher activated at that point, the aircraft would probably have pitched down to the extent that the aircraft would have contacted the ground at a high rate of descent in a nose-down attitude.

At the time of stick shaker activation, the pitch of the aircraft was increasing rapidly, the airspeed was decreasing, the thrust was at idle, and the flaps were full down. The descent was arrested; however, the aircraft was then in a nose-high attitude, with the flaps still down, and still with idle thrust. Considering the above, the darkness, the poor visibility, and the aircraft's position relative to the runway, it was concluded unlikely that at this point the crew could have landed the aircraft safely or completed a go-around without ground contact.

2.3.7 Wing Anti-Ice Procedures

Even though the aircraft would be flying into weather conditions that were conducive to ice formation, in accordance with the applicable procedures, the use of wing anti-ice was not required until the ice-detection system indicated the presence of ice; consequently, the anti-ice system was not turned on. If the Fredericton weather reports had indicated freezing fog rather than fog, it is probable that the actions by the crew would not have been different, as they would still follow the anti-ice procedures for the aircraft. Analysis indicates that even though a layer of ice as much as 0.020 inch thick could have accumulated on the leading edges of the wings during the final stages of the approach, the presence of ice would not have been indicated until the threshold of ice detection was reached and would not have been indicated at all below a radio altitude of 400 feet.

Because even an average thickness of 0.020 inch on the leading edge of the aircraft's wing could lower the stalling AOA by five degrees, the procedure to not select anti-ice ON until an indication of ice is annunciated, together with the inhibiting of ice indications below 400 feet, could result in a detrimental amount of ice being on the wing during landing or go-around. In the circumstances that existed for the occurrence flight, and with the limitations of the ice-detection and annunciation systems, the procedures on the use of wing anti-ice did not ensure a clean wing during the go-around. In more general terms, the procedures on the use of wing anti-ice did not ensure that the wing would remain ice-free during flight.

In addition, the implications of ice build-up below the threshold of detection and the inhibiting of the ice caution below 400 feet were not adequately considered with regard to the reduction of the stall margin during the 1996 certification of the ice-detection system and associated procedures.

2.3.8 Runway Length

The calculations made prior to the occurrence flight showed that the runway met the landing requirements of the *AFM.* These calculations were based on a wet runway and included a 60% factor that caters to runway JBI numbers above 0.40.

Calculations based on the aircraft landing from the point that the go-around was initiated indicate that completing a landing and stopping on the runway would have been possible: this is not to say that the aircraft would have stopped on the runway. However, there was no certainty that the aircraft could have been positioned properly over the runway and landed while still maintaining adequate safety margins. The captain's decision to go around when he assessed that the landing could not be completed safely was in accordance with established procedures and good airmanship.

2.4 Wing Performance Issues

2.4.1 Introduction

The investigation revealed that when the aircraft stalled, the aerodynamic performance of the wing was significantly degraded from the expected performance based on certification flight test data. The wing stalled at an AOA of about 9 degrees and a C_{Lmax} of 2.06, compared to expected values of 13.5 and 2.32. A number of factors that had the potential to contribute to the performance degradation were identified during the investigation and these will be discussed to determine the contribution of each to the performance of the wing.

2.4.2 Analysis of C_L-Alpha Curves

The computed C_L-alpha curves (shown at Appendix C) indicate degraded performance at the lower AOAs and show C_L values above those expected just prior to the stall. Although the expected curve was calculated using the same method as was used for the Bombardier computed curve, the flight dynamics for the expected data were closely controlled and this fact would account for some minor variations between the expected and computed curves. The higher C_L values of the computed curves approaching the stall are partly attributable to the fact that the expected curve is for free air (out of ground effect). Ground effect would shift the expected curve to the left and thus place the computed C_L values below the expected curve. In addition, the situation approaching the stall is not quasi-static, and there may be some dynamic stall effect resulting in higher C_L values just prior to the stall.

2.4.3 Analysis of Simulator Results

As stated, the comparison of the simulator model with the FDR data showed two distinct aerodynamic events while the aircraft was on approach. Both events resulted in increases in pitch angle and decreases in lift. From the changes in lift and rolling moment, the effective spanwise moment arm of the lift loss was calculated to be 20 feet, or in the area of wing station (WS) 240. This is the general area of the spoileron and of the leading edge cap located between WS 247 and WS 253.

There are two mechanisms that would translate into a lift loss in this area of the wing, a spoileron deflection (uncommanded) or a local flow separation. There was no indication of a spoileron deflection on the FDR. In addition, spoileron deflection would produce a negative yawing moment (nose-left) rather than the positive moment (nose-right) indicated and, therefore, can be eliminated. It was concluded that local flow separation in these areas must be considered a likely reason for the lift losses noted, particularly with the chordwise sealant at both of these wing stations protruding up to 3 mm above the surface of the leading edge cap. When considering local flow separation, the local change in drag, and thus the direction of the yawing moment, will depend on the relative magnitudes of the increase in profile drag compared to the decrease in induced drag. There were no flight test or other data available that would permit these relative magnitudes to be determined; however, this does not materially affect the conclusion that local flow separation caused the lift losses.

2.4.4 Factors Affecting Performance Loss

2.4.4.1 Wing Condition

Wing Paint

The paint just aft of the leading edge was cracked and, in certain places, was peeling or flaking. This painted area starts at the 8% chord position on the wing. The stall on the CL-65 wing occurs well forward of this 8% position and therefore the contribution of the paint condition to the stall would be negligible. The paint condition would result in a small increase in drag and could have a slight effect on the lift curve slope.

Leading-Edge Pitting

Bombardier Inc. concluded that the aerodynamic effect of the surface pitting was negligible. This assessment was based on previous flight-test and wind-tunnel data. The drag coefficient calculations for aircraft 104 showed a reduction in drag from flight 1 to flight 2 when the leading edge was polished; however, the estimated error range for these calculations was similar to the magnitude of the difference in drag coefficients and therefore no meaningful conclusions can be drawn. It is likely that there is some small effect from the surface pitting but that this effect was insignificant as far as the performance degradation of the accident aircraft was concerned.

Sealant

As determined by flight test, the extruded sealant on the leading edge of the wing of the accident aircraft could have resulted in a decrease of 1.7 to 2.0 degrees in maximum fuselage AOA and of 0.03 to 0.05 in C_{Lmax}. The sealant extrusions probably remained relatively constant over a considerable time period, and it is assumed that this magnitude of degradation was present throughout and prior to the flight.

2.4.4.2 Ground Effect

The performance reduction noted on the accident flight at the point that the aircraft stalled was approximately 4.5 degree in maximum fuselage AOA and 0.26 in C_{Lmax}. The study on ground effect estimated that at the minimum height above ground reached by the aircraft just prior to the stall (approximately 10 to 20 feet), the contribution of ground effect would have been approximately 0.3 degree of AOA. Given the considerable uncertainty associated with this estimate, the maximum reduction in AOA resulting from ground effect is considered to be in the order of 0.75±0.5 degrees. If this was the case, then the other factors which caused the reduction in performance accounted for approximately 3 to 4 degrees of AOA.

2.4.4.3 Ice Accretion

The ice accretion studies concluded that the aircraft was in an icing environment for at least 60 seconds prior to the stall, and that during this period a thin layer of mixed ice with some degree of roughness likely accumulated on the leading edges of the wings. The engineering simulator comparison indicated that aerodynamic "events" occurred at 400 and 150 feet agl that reduced the aircraft lift, and that the lift losses were a result of local flow separation in the area of the leading edge cap, located between WS 247 and WS 253.

The drag coefficient calculated for the accident flight (while the aircraft was on approach below

1000 feet) was significantly higher than the drag coefficients calculated for the previous flights. This difference in coefficients indicates increased drag while the aircraft was on approach, and, therefore, reduced performance.

The ice accretion study by Bombardier Inc. also stated that for the ice roughness, height, and density predicted, a reduction in lift of as much as 0.43±0.04 in C_{Lmax} with a corresponding change in maximum AOA of 5±1.25 degrees could be expected. The contributions of sealant and ground effect to the performance degradation have been estimated in previous sections, and, when combined, amount to between 2 and 3.3 degrees reduction in maximum AOA. The aircraft stalled at an AOA which was approximately 4.5 degrees lower than expected for the natural stall. The estimated effects of ice accretion, therefore, would be a reduction in maximum AOA of 2.5 degrees (4.5 - 2) to 1.2 degrees (4.5 - 3.3); a thin layer of ice could account for this degradation.

Notwithstanding that no ice was found on the aircraft following the accident, there is no phenomenon other than ice accretion that could account for performance deficits of this magnitude, particularly when progressive performance reductions occurred while the aircraft was on final approach in weather conditions conducive to icing. The most likely scenario is that in addition to ice accretion along the leading edge, ice also accumulated on the extruded sealant at WS 247 and WS 253.

2.4.4.4 Flap Movement

The flaps had just started to move when the aircraft stalled and, although there was probably some effect on lift and drag, the overall effect on the aircraft stalling was concluded to have been minimal.

2.4.4.5 Interactions of Lift-degrading Factors

The above analysis of the effect of the potential performance-degrading factors deals with each factor independently and does not consider any possible interactions between factors. For example, how would the extruded sealant affect the rate and location of ice accretion on the wing? There is undoubtedly some interaction between factors; however, to attempt to quantify these interactions would be very difficult and, perhaps, not possible. It is the opinion of the aerodynamic specialists assisting in this investigation that the magnitude of any interactions would be small compared to the magnitude of the individual influences of sealant, ice accretion, and ground effect.

2.4.4.6 Performance Loss Summary

With respect to wing performance, the most likely scenario for the accident flight is as follows:

- -The aircraft departed Toronto with the wings in a condition such that there was a loss of performance over that expected from production wings.
- -The aircraft entered icing conditions at approximately 1000 feet agl on approach to Fredericton.
- -A thin layer of ice began to accumulate on the leading edges of the wings, with an increased accumulation rate in the area of the WS 247 and WS 253.
- -The ice accumulation rate was insufficient to trip the ice detection warning prior to the system being inhibited at 400 feet agl.
- -Ice continued to accumulate on the wings, further degrading the wing performance.

2.4.5 Stall Protection System--Certification and Functioning

Analysis of the SPS in general, and of the SPS shaker and pusher trip points in particular, shows that the system performed as designed. The pusher is designed to prevent the aircraft from reaching the aerodynamic stall; however, the aircraft *did* stall aerodynamically before the pusher activated. From a purely aerodynamic perspective, this stall occurred because the wing's performance was degraded by the condition of the wing and by surface contamination to the extent that, for the flight conditions that existed at the time, the aerodynamic stall occurred just prior to pusher activation. In these circumstances, the margin between the pusher and the aerodynamic stall essentially disappeared as the wing performance was degraded.

Although stall identification, as intended by the SPS certification, was not provided by the pusher in this particular case, SPS performance does not appear to be an issue. The two factors identified that resulted in the performance loss can be eliminated through changes to maintenance procedures and to operating procedures for the ice detection and anti-ice systems.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

- Although for the time of the approach the weather reported for Fredericton--ceiling 100 feet and visibility mile--was below the 200-foot decision height and the charted ½ -mile (RVR 2600) visibility for the landing, the approach was permitted because the reported RVR of 1200 feet was at the minimum RVR specified in CAR 602.129.

- Based on the weather and visibility, runway length, approach and runway lighting, runway condition, and the first officer's flying experience, allowing the first officer to fly the approach is questionable.

- The first officer allowed the aircraft to deviate from the flight path to the extent that a go-around was required, which is an indication of his ability to transition to landing in the existing environmental conditions.

- Disengagement of the autopilot at 165 feet rather than at the 80-foot minimum autopilot altitude resulted in an increased workload for the PF, allowed deviations from the glide path, and deprived the pilots of better visual cues for landing.

- In the occurrence environmental conditions, the lack of runway centre line and touchdown-zone lighting probably contributed to the first officer not being able to see the runway environment clearly enough to enable him to maintain the aircraft on the visual glide path and runway centre line.

- The first officer's inexperience and lack of training in flying the CL-65 in low-visibility conditions contributed to his inability to successfully complete the landing.

- The situation of a captain being the PNF when ordering a go-around probably played a part in the uncertainty regarding the thrust lever advance and the raising of the flaps because there was no documented procedure covering their duties.

- The go-around was attempted from a low-energy situation outside of the flight boundaries certified for the published go-around procedures; the aircraft's low energy was primarily the result of the power being at idle.

- The sequential nature of steps within the go-around procedures, in particular, in directing the pitch adjustment prior to noting the airspeed, the compelling nature of the command bars, and the high level of concentration required when initiating the go-around contributed to the first officer's inadequate monitoring of the airspeed during the go-around attempt.

- Following the command bars in go-around mode does not ensure that a safe flying speed is maintained, because the positioning of the command bars does not take into consideration the airspeed, flap configuration, and the rate of change of the

angle of attack, considerations required to compute stall margin.

- The conditions under which the go-arounds are demonstrated for aircraft certification do not form part of the documentation that leads to aircraft limitations or boundaries for the go-around procedure; this contributed to these factors not being taken into account when the go-around procedures were incorporated in aircraft and training manuals.

- The published go-around procedure does not adequately reflect that once power is reduced to idle for landing, a go-around will probably not be completed without the aircraft contacting the runway (primarily because of the time required for the engines to spool up to go-around thrust).

- The Air Canada stall recovery training, as approved by Transport Canada, did not prepare the crew for the conditions in which the occurrence aircraft stick shaker activated and the aircraft stalled.

- The limitations of the ice-detection and annunciation systems and the procedures on the use of wing anti-ice did not ensure that the wing would remain ice-free during flight.

- Ice accretion studies indicate that the aircraft was in an icing environment for at least 60 seconds prior to the stall, and that during this period a thin layer of mixed ice with some degree of roughness probably accumulated on the leading edges of the wings. Any ice on the wings would have reduced the safety margins of the stall protection system.

- The implications of ice build-up below the threshold of detection, and the inhibiting of the ice advisory below 400 feet, were not adequately considered when the stall margin was being determined during the 1996 certification of the ice-detection system and associated procedures.

- The stall protection system operated as designed: that it did not prevent the stall is related to the degraded performance of the wings.

- The Category I approach was without the extra aids and defences required for Category II approaches.

- Canadian regulations with respect to Category I approaches are more liberal than those of most countries and are not consistent with the ICAO *International Standards and Recommended Practices* (Annex 14), which defines visibility limits; in Canada, the visibility values, other than RVR, are advisory only.

- Even though a Category I approach may be conducted in weather conditions reported to be lower than the landing minima specified for the approach, there is no special training required for any flight crew member, and there is no requirement that flight crew be tested on their ability to fly in such conditions.

- Air Canada's procedures required that the captain fly the aircraft when conducting a Category II approach, in all weather conditions; however, the decision as to who will fly low-visibility Category I approaches was left to the captain, who may not be in a position to adequately assess the first officer's ability to conduct the approach.

- The aircraft stalled at an angle of attack approximately 4.5 degrees lower, and at a C_{Lmax} 0.26 lower, than would be expected for the natural stall.

- On final approach below 1000 feet agl, the wing performance on the accident flight was degraded over the wing performance at the same phase on the previous flight.

- The engineering simulator comparison indicated two step reductions in aircraft performance, at 400 feet and 150 feet agl, as a result of local flow separation in the vicinity of wing station (WS) 247 and WS 253.

- Pitting on the leading edges of the wings had a negligible effect on the performance of the aircraft.

- The sealant on the leading edges of both wings was missing in some places and protruding from the surface 2 to 3 mm in others. Test flights indicate that the effect of the protruding chordwise sealant on the aircraft performance could have accounted for a reduction of 1.7 to 2.0 degrees in maximum fuselage angle of attack and of 0.03 to 0.05 in C_{Lmax}.

- The maximum reduction in angle of attack resulting from ground effect is considered to be in the order of 0.75±0.5 degree: the aircraft angle of attack was influenced by ground effect during the go-around manoeuvre.

- The performance loss caused by the protruding sealant and by ground effect was not great enough to account for the performance loss experienced; there is no apparent phenomenon other than ice accretion that could account for the remainder of the performance loss.

- Neither Bombardier Inc., nor Transport Canada, nor Air Canada ensured that the regulations, manuals, and training programs prepared flight crews to successfully and consistently transition to visual flight for a landing or to go-around in the conditions that existed during this flight, especially considering the energy state of the aircraft when the go-around was commenced.

3.2 Other Findings

- Both the captain and the first officer were licensed and qualified for the duties performed during the flight in accordance with regulations and Air Canada training and standards, except for minor training deficiencies with regard to emergency equipment.

- The occurrence flight attendant was trained and qualified for the flight in accordance with existing requirements.

- The aircraft was within its weight and centre-of-gravity limits for the entire flight.

- Records indicate that the aircraft was certified, equipped, and maintained in accordance with existing regulations and approved procedures.

- There was no indication found of a failure or malfunction of any aircraft component prior to or during the flight.
- When the stick shaker activated, it is unlikely that the crew could have landed the aircraft safely or completed a go-around without ground contact.

- When power was selected for the go-around, the engines accelerated at a rate that would have been expected had the thrust levers been slammed to the go-around power setting.

- The aircraft was not equipped with an emergency locator transmitter, nor was one required by regulation.

- The lack of an emergency locator transmitter probably delayed locating the aircraft and its occupants.

- Passengers and crew had no effective means of signalling emergency rescue services personnel.

- The flight crew did not receive practical training on the operation of any emergency exits during their initial training program, even though this was required by regulation.

- Air Canada's initial training program for flight crew did not include practical training in the operation of over-wing exits or the flight deck escape hatch.

- Air Canada's annual emergency procedures training for flight crew regarding the operation and use of emergency exits did not include practical training every third year, as required. Annual emergency exit training was done by demonstration only.

- The flight crew were unaware that a pry bar was standard emergency equipment on the aircraft.

- The four emergency flashlights carried on board were located in the same general area of the aircraft, increasing the possibility that all could be rendered inaccessible or unserviceable in an accident. (See section 4.1.6)

- That there was a Flight Service Station specialist, as opposed to a tower controller, at the Fredericton airport at the time of the arrival of ACA 646 was not material to this occurrence.

4.0 Safety Action

4.1 Action Taken

4.1.1 Use of Aircraft Anti-Ice

It was discovered during the investigation that operating procedures, combined with the limitations of the ice-detection system, would not ensure that the aircraft wings and engines would be free of ice during flight.

On 11 March 1998, to address the issue of the "ICE" caution being inhibited below the radio altitude of 400 feet agl, Air Canada issued Aircraft Technical Bulletin No. 158 amending the procedures in its *AOM* (Volume 2/02.00- .02/ .30- .43) as follows:

During flight, the engine cowl and wing anti-ice system must be ON when:

i) icing conditions are indicated by the ice detection system, or

ii) there is visual detection of ice formation on the airplane surfaces (windshield wipers, window frames, etc.), or

iii) operating below 400 agl and icing conditions exist as defined by the AOM,

Vol. 2, 02.17.01, or

iv) an ice detector has failed and icing conditions exist as defined by the AOM,

Vol. 2, 02.17.01.

Bombardier Regional Aircraft Division, with Transport Canada approval, issued All Operator Message No. 234, dated 20 March 1998, referring to Temporary Revision RJ/61 which was sent to all CL-65 operators. The temporary revision consolidated and clarified icing definitions and procedures for operation in icing conditions, as defined in the *Airplane Flight Manual*, CSP A-012, to ensure that the ice protection systems are activated whenever the aircraft is operating in conditions that could lead to ice accumulating on the wing and engine cowl leading edges.

The procedures outlined in Air Canada's Aircraft Technical Bulletin and in Bombardier's All Operator Message will reduce the possibility of ice accumulation on the CL-65 aircraft. Nevertheless, there is still a risk that while an aircraft is operating below 400 feet agl, ice could accumulate to an extent that aircraft performance would be materially affected without the pilots being aware that they had entered icing conditions or that ice had accumulated. If the amber ICE light were not inhibited below 400 feet, however, an extra safe-guard would be in place to alert pilots to the presence of ice.

The Federal Aviation Administration (USA) considers illumination of the amber ICE light to be a warning light, not a caution light. Consequently illumination of the amber light is not inhibited on CL-65 aircraft registered in the USA.

It is acknowledged that illumination of the amber ICE light at low altitude could introduce some risk by distracting the crew; however, this risk must be compared to the risk associated with the increased potential for ice accumulating during a critical stage of flight if illumination of the amber ICE light is inhibited. To reduce the risk of aircraft stall during a critical stage of flight, the TSB issued an Aviation Safety Advisory on 9 April 1999, suggesting that Transport Canada consider taking action to remove the inhibition of the amber ICE light below 400 feet agl on existing and future CL-65 aircraft.

4.1.2 Requirement for an Emergency Locator Transmitter

In reviewing the requirement for Emergency Locator Transmitters (ELTs), the TSB noted that under CAR 605.38(3), multi-engine turbo-jet aeroplanes of more than 5700 kg (12 500 pounds) maximum certified take-off weight, such as the Canadair CL-65, when operating in IFR flight within controlled airspace, over land, and south of latitude 6630' N, are not required to be equipped with an ELT. This "exemption" did not apply to non-turbo-jet aeroplanes (like the Dash-8 and ATR-42) which are similar to the CL-65 in terms of passenger capacity, operational environment, and engine reliability.

TSB information indicates that there is no significant difference in accident rates--between aeroplanes of similar size--strictly as a function of their being turbo-prop versus turbo-jet. Risk mitigation with respect to post-crash survivability that is gained by being equipped with an ELT, such as ELT-assisted search and rescue efforts, applies to all aircraft, regardless of the type of propulsion system.

On 24 February 1998 the TSB issued Aviation Safety Advisory 980004 , suggesting that Transport Canada consider reviewing CAR 605.38(3) with a view to eliminating the ELT carriage exemption for turbo-jet aircraft.

On 3 April 1998 Transport Canada reported that, given the concerns raised in TSB Advisory 980004 and the time interval since the original regulation was promulgated, the General Operating and Flight Rules Technical Committee of the Canadian Aviation Regulation Advisory Council had been tasked to review the adequacy of existing regulation regarding ELT requirements.

Transport Canada has since advised that the Civil Aviation Regulatory Committee, at its 11 December 1998 meeting, decided to initiate amendments to CAR 605.38 to require multi-engine turbo-jet aircraft of more than 5700 kg maximum certified take-off weight operating in IFR flight within controlled airspace to carry an ELT.

4.1.3 Aircraft Low-Energy Issues

When the go-around was initiated, the aircraft was configured for landing, it was at a low height above the runway, the airspeed was decreasing, and the engines were at idle. The aircraft was not able to complete the go-around manoeuvre without ground contact because it was in a low-energy state.

On 13 May 1998 Transport Canada issued a Commercial and Business Aviation Advisory Circular to notify pilots and air operators of the potential hazards associated with a balked landing or go-around. The circular states that an aircraft is not certified to successfully complete a go-around without ground contact once it has entered the low-energy landing regime. For the purposes of the circular, the low-energy landing regime is defined as follows:

1. aircraft flaps and landing gear are in the landing configuration;

2. aircraft is in descent;

3. thrust has stabilized in the idle range;

4. airspeed is decreasing; and

5. aircraft height is 50 feet* or less above the runway elevation.

* *Note: 50 feet is a representative value. A given aircraft may enter the low-energy landing regime above or below 50 feet in accordance with approved landing procedures for that type.*

The circular further stated that the decision to place an aircraft in the low-energy regime is a decision to land; if there is any doubt regarding the probability of a safe landing, a go-around must be initiated prior to entry into this regime. An attempt to commence a go-around or balked landing while in the low-energy landing regime is a high-risk, undemonstrated manoeuvre. In the extreme case where such action is required, pilots should be aware that ground contact is likely and any attempt to commence a climb before the engines have achieved go-around thrust may result in a stall.

The circular advised that air operators should immediately ensure that their pilots and training personnel are aware of the hazards associated with low-energy go-arounds or balked landings and verify that their training programs address the hazards inherent in, and procedures for dealing with, low-energy operations.

4.1.4 Procedures and Training

Air Canada has taken a number of actions as a result of information learned from this occurrence, as follows:

- the go-around procedure in the CL-65 *AOM* has been amended to amplify the importance of airspeed during a go-around;

- a NOTE has been added to the CL-65 *AOM* stating that when a go-around is executed in close proximity to the ground, landing gear ground contact may occur;

- the CL-65 pilot training program has been amended to include information on

low-energy go-arounds; and

- the *FOM* (publication 550), has been amended to include more definitive and conservative requirements regarding low-visibility approaches.

4.1.5 CL-65 Wing Maintenance

In response to the wing surface condition noted on the accident aircraft, Air Canada made some changes to the maintenance of the wings on their CL-65 fleet, to improve their overall condition and, thereby, enhance the aerodynamic performance of the aircraft. These changes supplement the leading-edge maintenance recommended by Bombardier Inc. and consist of the following:

- washing and polishing of the leading edge at 60-day intervals,

- replacing the sealant used on the leading edge with an improved sealant,

- inspecting and restoring the leading edge sealant at each "A" check (every 400 hours),

- repainting wing surfaces as required, based on a C2 segment (2250 hours) inspection.

4.1.6 Safety Information Letters

When an unsafe condition is noted for which remedial action is not immediately required, the TSB staff may draw this to the attention of appropriate regulatory or corporate officials with a safety information letter. These letters are generally concerned with local hazards or with unsafe conditions posing relatively low risks.

Three information letters were sent to Transport Canada regarding TSB observations from this investigation, on the following: flight crew emergency procedures training on the operation of emergency exits; location of emergency equipment, in particular the flashlights; and the provision of signalling tools as part of the survival equipment.

Both Transport Canada and Air Canada have responded to the above-noted safety information letters. A summary of their intended or completed remedial action follows:

- Transport Canada will develop Commercial and Business Aviation Advisory Circulars for air operators, and Policy Letters for Commercial and Business Aviation Inspectors responsible for the approval of flight crew member training programs. These documents are being developed to clarify the intent of the "emergency exits" training requirement, as well as the training requirements for the location and use of emergency equipment, including practical training. Appropriate amendments to the Commercial Air Service Standards will be proposed by Transport Canada.

- Transport Canada will develop a Commercial and Business Aviation Advisory Circular, for air operators, to recommend that on aircraft types where only one flight attendant is carried and the flight attendant seat is located forward, an additional flashlight be carried on that aircraft and that it be located in the rear of the aircraft.

- Air Canada has published Insert No. 72 to their Flight Attendant Manual (Publication 356), regarding the carriage of an additional flashlight in the aft of the CL-65 aircraft.

- Transport Canada advised that they will be establishing a working group to review the current survival equipment regulation and all associated issues and concerns; the TSB's concern regarding a "means for signalling distress" will be included.

4.1.7 Practical Training

During the course of the investigation it was determined that Air Canada's CL-65 Flight Crew Training Program did not provide pilots with the required "hands-on" training on the operation and use of all emergency exits. Transport Canada subsequently responded to a TSB information letter on this issue indicating that action would be taken to enhance operator and Transport Canada inspector awareness of requirements for this training.

Transport Canada's response to the information letter indicated that Transport Canada would take appropriate action to enhance awareness of the requirements for emergency exit training. However, other information from Transport Canada has indicated that a regulatory requirement for "practical training" does not necessarily include direct, "hands-on" training. This indicates that there may be a more wide-spread problem concerning differing interpretations of the meaning of the term "practical training" by Transport Canada inspectors and industry (beyond that applicable to just emergency exits). Differing interpretations by Transport Canada inspectors, or by operators, could result in the associated regulations and standards being applied differently and hands-on training not being provided where intended. Therefore, the TSB issued an Aviation Safety Advisory on 9 April 1999, suggesting that Transport Canada consider taking action to avoid misunderstandings of the meaning of, and requirements for, "practical training."

4.2 Action Required

4.2.1 Low-Weather Approaches

The reported weather at Fredericton at the time of the accident was: vertical visibility 100 feet obscured, horizontal visibility one-eighth of a mile in fog, and runway visual range 1200 feet. After the autopilot was disengaged at 165 feet above ground, the aircraft deviated from the desired flight path. The captain subsequently ordered a go-around because he was not sure that a safe landing could be made on the runway remaining. Given the low-energy state of the aircraft, and the crew's uncertainty about the amount of runway remaining, the margin of safety for the flight was significantly compromised.

A review of occurrences involving large aircraft landing in poor visibility was conducted for the period from 1 January 1984 to 30 June 1998. In the United States, there were 18 such occurrences recorded as attributable to poor visibility; most led to aircraft damage and had at least the potential of causing injury to those on board. In Canada, there were 28 such occurrences, the most serious being this occurrence. In only one of the Canadian occurrences was a Category II approach being conducted.

Canadian regulations permit Category I approaches to be flown in visibilities lower than would be permitted in most other countries (including the United States), and the regulations are not consistent with what is recommended in ICAO *International Standards and Recommended Practices*. ICAO Annex 14 recommends the use of visibility limits whereby pilots are not permitted to carry out an approach if the reported visibility is below the limit specified for the approach. In Canada, however, the visibility values, other than RVR, are advisory only; pilots are permitted to carry out an approach regardless of the visibility, and continue descent to ground level if they have acquired the runway environment. If an airport is RVR equipped, RVR visibility limits do apply in Canada; however, these limits are lower in Canada for a Category I approach than they are in other countries (including the United States). Although an approach for landing is not permitted if the RVR for a runway is below limits, the number of approaches conducted in poor visibility in Canada will likely increase because NAV CANADA is reducing the number of airports served by RVR equipment.

To compensate for the risk associated with landing an aircraft in conditions of low ceiling and visibility, extra aids and defences should be in place. These can take the form of special operating requirements for equipment, training, experience, and procedures. Section 1.18.2.1 of this report details the demanding operating requirements applicable to Category II approaches. As demonstrated by this accident, however, Canadian regulations permit Category I approaches to be conducted in weather conditions equivalent to or lower than Category II landing minima without the benefit of the operating requirements applicable to Category II approaches. Therefore, to reduce the risk of accidents in poor weather during the approach and landing phases of flight, the Board recommends that:

The Department of Transport reassess Category I approach and landing criteria (re-aligning weather minima with operating requirements) to ensure a level of safety consistent with Category II criteria.

A99-05

4.2.2 Low-Energy Go-arounds

Transport Canada issued a Commercial and Business Aviation Advisory Circular to notify pilots and air operators of the potential hazards associated with conducting a go-around once an aircraft has entered the low-energy landing regime. The circular advised that air operators should immediately ensure that their pilots and training personnel are aware of the hazards associated with low-energy go-arounds and verify that their training programs address these hazards and provide procedures for dealing with them. Dissemination of the advisory circular should reduce the risk of accidents involving low-energy go-arounds in the short term.

Advisory circulars are intended to provide information and guidance regarding operational matters; they do not become a formal part of the safety requirements established by Transport Canada. In the absence of formal entrenchment in the aviation system, these advisory circulars tend to lose their information value as newer circulars on other topics appear. Since the importance of knowledge of low-energy go-arounds will not decrease over time, some process is required to ensure that new pilots are informed of, and experienced pilots maintain their awareness of, the risks involved. Therefore, the Board recommends that:

The Department of Transport ensure that pilots operating turbo-jet aircraft receive training in, and maintain their awareness of, the risks of low-energy conditions, particularly low-energy go-arounds.

A99-06

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board, consisting of Chairperson Benoît Bouchard, and members Maurice Harquail and W.A. Tadros, authorized the release of this report on 15 April 1999.

5.0 Appendices

Appendix A - Fredericton Approach Plate for ILS-15

Appendix B1 - Aircraft Wreckage Plot

Appendix B2 - Wreckage Plot Code

Appendix C - Computed Versus Expected C_L-Alpha Curve

Appendix D - List of Supporting Reports

The following TSB Engineering Branch Reports were completed and are available on request:

LP 28/98 Records Group Report--CL-600-2B19, C-FSKI
LP 192/97 Recorders Group Report
Flight reconstruction video

LP 11/98 Structures Group Report
LP 191/97 Site Survey
LP 3/98 Stall Protection System Components Testing
LP 41/98 Bending Strength of Crash Axe and Pry Bar

Appendix E - Glossary

ACA646 Air Canada Flight 646
ACARS aircraft communications and reporting system
ACC area control centre
AFCS automatic flight control system
AFM Canadair Regional Jet Airplane Flight Manual
agl above ground level
AOA angle of attack
AOM CL-65 Airplane Operating Manual (Air Canada)
asl above sea level
AST Atlantic standard time
ATC air traffic control
C_L coefficient of lift
CARs Canadian Aviation Regulations
CASSs Commercial Air Service Standards
CBAA Commercial & Business Aviation Advisory Circular
CVR cockpit voice recorder
DA/H decision altitude/height
DME distance measuring equipment
EICAS Engine Indicating and Crew Alerting System
ELT emergency locator transmitter
EST eastern standard time
FCOM Flight Crew Operating Manual
FDR flight data recorder
FMS flight management system
FOM Flight Operations Manual (Air Canada Publication 550)
FSS Flight Service Station
G unit of acceleration equal to the force of gravity
IAR Institute of Aviation Research (division of National Research Council of Canada)
IAS indicated airspeed
ICAO International Civil Aviation Organization
IFR instrument flight rules
IFT instrument flight test
ILS instrument landing system
JBI James brake index
kg kilograms
kHz kilohertz

KIAS knots indicated airspeed
MDA minimum descent altitude
MDA/H minimum descent altitude/height
mg milligram
MHz megahertz
NDB non-directional beacon
NOTAM Notice to Airmen
NRC National Research Council of Canada
PA passenger address
PF pilot-flying
PMA pilot monitored approach
PNF pilot-not-flying
PPC pilot proficiency check
QETE Quality Engineering Test Establishment
RCMP Royal Canadian Mounted Police
RVR runway visual range
sm statute mile
SOPs standard operating procedures
SPS stall protection system
TCAS traffic-alert collision-avoidance system
TOGA take-off and go-around
TSB Transportation Safety Board of Canada
UTC coordinated universal time
V_2 take-off safety speed
V_{APP} (normally) approach speed with one engine inoperative
VFR visual flight rules
VHF very high frequency
VOR very high frequency omni-directional range
V_{REF} approach speed--landing reference speed in the normal landing configuration
WS wing station
degree